

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CALLAWAY GOLF COMPANY,

Plaintiff,

v.

ACUSHNET COMPANY,

Defendant.

Civil Action No. 07 - 367

COMPLAINT AND DEMAND FOR JURY TRIAL

2007 JUN -8 PM 3:54
U.S. DISTRICT COURT
DISTRICT OF DELAWARE

For its Complaint, Callaway Golf alleges:

PARTIES

1. Plaintiff Callaway Golf Company ("Callaway Golf") is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business in Carlsbad, California.

2. Defendant Acushnet Company ("Acushnet"), upon information and belief, is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business in Fairhaven, Massachusetts.

3. Acushnet, upon information and belief, is a wholly-owned operating company of Fortune Brands, Inc. ("Fortune Brands").

4. Fortune Brands, upon information and belief, is a publicly-traded corporation organized and existing under the laws of the State of Delaware.

JURISDICTION AND VENUE

5. This Court has subject matter jurisdiction under 28 U.S.C. §§ 1331 and 1338(a).

6. Acushnet is subject to personal jurisdiction in this District because, upon information and belief, Acushnet is a Delaware corporation and is doing and has done substantial business in this District, including business relating to the sale and distribution for sale of the infringing products as described below.

7. Venue is proper in this judicial district pursuant to 28 U.S.C. § 1400(b).

BACKGROUND

Callaway Golf's Patents For Golf Club Heads Having A Striking Face With Improved Impact Efficiency

8. Dr. John B. Kosmatka, Professor of the Jacobs School of Engineering at the University of California, San Diego ("USCD"), has consulted with Callaway Golf on several aspects of golf club design. Dr. Kosmatka's consulting agreement with Callaway Golf complied with all of USCD's requirements for such a consulting agreement and provided that all inventions created during the consulting activities were to be assigned to Callaway Golf.

9. During his consulting activities for Callaway Golf, Dr. Kosmatka invented breakthrough technology relating to golf club construction, particularly the design of compliant golf club heads that permit more efficient impact between a golf ball and the golf club head, resulting in performance that had previously eluded the industry.

10. Dr. Kosmatka has been awarded several patents for his work on golf club design including U.S. Patent Nos. 6,348,015, 6,478,692, 6,669,579, 6,685,576, and 6,949,032 patents (collectively "the Kosmatka patents"). Pursuant to his consulting agreement, Dr. Kosmatka assigned his inventions and the resulting Kosmatka patents to Callaway Golf.

11. Callaway Golf has had success selling golf clubs embodying the technology

claimed in the Kosmatka patents.

12. Acushnet makes and sells golf clubs under the Titleist® and Cobra® brands, including drivers that embody one or more claims of each of the Kosmatka patents. The Acushnet clubs that infringe one or more of the Kosmatka patents include, but are not limited to, the King Cobra 454 Comp, King Cobra F Speed, King Cobra HS9 F Speed, King Cobra HS9 M Speed, and King Cobra LD F Speed, Titleist 905R, Titleist 905S, and Titleist 905T clubs.

Acushnet's Breach Of The 1996 Settlement Agreement

13. In 1996, Callaway Golf's predecessor-in-interest, Spalding World Wide Sports Inc., ("Spalding") sued Acushnet for patent infringement regarding two-piece golf ball technology. To resolve Spalding's claims of patent infringement and Acushnet's related unfair competition counter-claims, the parties entered into a settlement agreement on August 5, 1996. Among the terms and conditions of the settlement agreement is the requirement that the parties resolve any and all patent-related disputes exclusively via a lawsuit in this Court. Specifically, the parties agreed in relevant part that "[a]ny dispute arising out of or relating to patents . . . shall be resolved in accordance with the procedures specified in this Section, which shall be the sole and exclusive procedure for resolution of any disputes." The 1996 Settlement Agreement goes on to specify that after the parties undertake a multi-step, pre-lawsuit dispute resolution process, including mediation before Magistrate Judge Thyne, "either party may initiate legal proceedings, but only in the United States District Court for the District of Delaware, and no other. Said court retains jurisdiction of the parties for such purposes." The 1996 Settlement Agreement remains in effect today and this Court retains jurisdiction over any disputes "arising out of or relating to

patents” between the parties.

14. In August 2004, Callaway Golf initiated the pre-lawsuit dispute resolution procedures mandated by the 1996 Settlement Agreement relative to a patent dispute over golf ball patents. Callaway Golf and Acushnet both acknowledged that Callaway Golf was obligated to follow the procedures in the 1996 Settlement Agreement as a successor to Spalding. Moreover, section 15 of the 1996 Settlement Agreement specifies that the 1996 Settlement Agreement “is binding upon the parties hereto . . . as well as their representatives, successors, transferees and assigns of substantially all of the their respective Golf Ball Businesses.”

15. For approximately the next 18 months, the parties engaged in the pre-lawsuit dispute resolution procedure mandated by the 1996 Settlement Agreement with respect to the golf ball patent dispute. Specifically, Acushnet and Callaway Golf engaged in negotiations by and between senior executives in an attempt to resolve the dispute. In addition, as required by the settlement agreement, the parties participated in mediation with a third-party professional mediator, as well as several mediation sessions before Magistrate Judge Thyng of this Court.

16. On or about January 17, 2006, Acushnet breached the terms and conditions of the 1996 Settlement Agreement by filing four *inter partes* reexamination requests with the PTO for Callaway Golf’s golf ball patents, numbers, 95/000120-123.

17. Callaway Golf filed suit in this Court on February 9, 2006, in accordance with the terms of the 1996 Settlement Agreement. In its complaint, Callaway Golf accused Acushnet of infringing the four golf ball patents.

18. On June 15, 2006, Callaway Golf moved to amend its complaint to add a claim

for Acushnet's breach of the 1996 Settlement Agreement.

19. Acushnet opposed Callaway Golf's motion to amend. In its opposition, Acushnet argued that the 1996 Settlement Agreement "does not in any way purport to apply to disputes between Acushnet and **non-parties** to the Agreement, like Callaway." (Emphasis in original.) Acushnet also argued that the amendment should be denied because "[o]n its face, the 1996 Agreement only applies to disputes between Acushnet and Spalding (the 'parties' to the agreement)." It therefore is Acushnet's present view that the 1996 Agreement does not apply to disputes, like this one, involving Acushnet and Callaway Golf.

20. On October 18, 2006, the Court granted Callaway Golf's motion to amend its complaint to add the affirmative claim for breach of the 1996 Settlement Agreement.

**Acushnet's Breach Of The 1996 Settlement Agreement
In Connection With This Dispute**

21. On April 3, 2007, Callaway Golf brought this new dispute relating to the Titleist and Cobra brand golf clubs to Acushnet's attention and asked Acushnet to confirm its alleged belief that the 1996 Settlement Agreement did not relate to disputes between Acushnet and Callaway Golf.

22. Faced with this new dispute, Acushnet backed away from its previous argument that the 1996 Settlement Agreement did not apply to disputes between Acushnet and Callaway Golf. Rather, in letters dated April 9 and April 19, 2007, Acushnet stated that it needed to know the patents at issue in the new dispute in order to "evaluate" whether the 1996 Settlement Agreement applied to this new dispute over golf club patents. Acushnet's response was in direct conflict with the arguments it previously made regarding the scope of the 1996 Settlement

Agreement. Moreover, Acushnet's prior refusal to confirm that that the 1996 Settlement Agreement's dispute resolution procedures applied to the golf ball dispute and refusal to be bound by those procedures was another breach of the 1996 Settlement Agreement.

23. Given Acushnet's breaches of the 1996 Settlement Agreement, Callaway Golf files this action in this Court which properly has jurisdiction over the dispute relating to the Kosmatka patents.

COUNT I - INFRINGEMENT OF THE '015 PATENT

24. Callaway Golf incorporates and realleges the allegations of paragraphs 1 through 23 as if fully set forth herein.

25. Callaway Golf is the owner by assignment of United States Patent No. 6,348,015, entitled "Golf Club Head Having A Striking Face With Improved Impact Efficiency" ("the '015 patent"), which was duly and legally issued by the United States Patent and Trademark Office on February 19, 2002. A copy of the '015 patent is attached as Exhibit A to this Complaint.

26. Acushnet has infringed one or more claims of the '015 patent by making, using, selling and/or offering to sell infringing golf clubs.

27. Acushnet has and has had constructive notice of the '015 patent pursuant to 35 U.S.C. § 287(a).

28. On information and belief, Acushnet monitors the issuance of all patents that relate to golf clubs and was therefore aware of the '015 patent on or about the day it issued, and Acushnet's continued manufacture and sale of the infringing clubs despite knowledge of the patent constitutes willful infringement.

COUNT II - INFRINGEMENT OF THE '692 PATENT

29. Callaway Golf incorporates and realleges the allegations of paragraphs 1 through 23 as if fully set forth herein.

30. Callaway Golf is the owner by assignment of United States Patent No. 6,478,692, entitled "Golf Club Head Having A Striking Face With Improved Impact Efficiency" ("the '692 patent"), which was duly and legally issued by the United States Patent and Trademark Office on November 12, 2002. A copy of the '692 patent is attached as Exhibit B to this Complaint.

31. Acushnet has infringed one or more claims of the '692 patent by making, using, selling and/or offering to sell infringing golf clubs.

32. Acushnet has and has had constructive notice of the '692 patent pursuant to 35 U.S.C. § 287(a).

33. On information and belief, Acushnet monitors the issuance of all patents that relate to golf clubs and was therefore aware of the '692 patent on or about the day it issued, and Acushnet's continued manufacture and sale of the infringing clubs despite knowledge of the patent constitutes willful infringement.

COUNT III - INFRINGEMENT OF THE '579 PATENT

34. Callaway Golf incorporates and realleges the allegations of paragraphs 1 through 23 as if fully set forth herein.

35. Callaway Golf is the owner by assignment of United States Patent No. 6,669,579, entitled "Golf Club Head Having A Striking Face With Improved Impact Efficiency" ("the '579 patent"), which was duly and legally issued by the United States Patent and Trademark Office on

December 30, 2003. A copy of the '579 patent is attached as Exhibit C to this Complaint.

36. Acushnet has infringed one or more claims of the '579 patent by making, using, selling and/or offering to sell infringing golf clubs.

37. Acushnet has and has had constructive notice of the '579 patent pursuant to 35 U.S.C. § 287(a).

38. On information and belief, Acushnet monitors the issuance of all patents that relate to golf clubs and was therefore aware of the '579 patent on or about the day it issued, and Acushnet's continued manufacture and sale of the infringing clubs despite knowledge of the patent constitutes willful infringement.

COUNT IV - INFRINGEMENT OF THE '576 PATENT

39. Callaway Golf incorporates and realleges the allegations of paragraphs 1 through 23 as if fully set forth herein.

40. Callaway Golf is the owner by assignment of United States Patent No. 6,685,576, entitled "Golf Club Head Having A Striking Face With Improved Impact Efficiency" ("the '576 patent"), which was duly and legally issued by the United States Patent and Trademark Office on February 3, 2004. A copy of the '576 patent is attached as Exhibit D to this Complaint.

41. Acushnet has infringed one or more claims of the '576 patent by making, using, selling and/or offering to sell infringing golf clubs.

42. Acushnet has and has had constructive notice of the '576 patent pursuant to 35 U.S.C. § 287(a).

43. On information and belief, Acushnet monitors the issuance of all patents that

relate to golf clubs and was therefore aware of the '576 patent on or about the day it issued, and Acushnet's continued manufacture and sale of the infringing clubs despite knowledge of the patent constitutes willful infringement.

COUNT V - INFRINGEMENT OF THE '032 PATENT

44. Callaway Golf incorporates and realleges the allegations of paragraphs 1 through 23 as if fully set forth herein.

45. Callaway Golf is the owner by assignment of United States Patent No. 6,949,032, entitled "Golf Club Head Having S Striking Face With Improved Impact Efficiency" ("the '032 patent"), which was duly and legally issued by the United States Patent and Trademark Office on September 27, 2005. A copy of the '032 patent is attached as Exhibit E to this Complaint.

46. Acushnet has infringed one or more claims of the '032 patent by making, using, selling and/or offering to sell infringing golf clubs.

47. Acushnet has and has had constructive notice of the '032 patent pursuant to 35 U.S.C. § 287(a).

48. On information and belief, Acushnet monitors the issuance of all patents that relate to golf clubs and was therefore aware of the '032 patent on or about the day it issued, and Acushnet's continued manufacture and sale of the infringing clubs despite knowledge of the patent constitutes willful infringement.

PRAYER FOR RELIEF

WHEREFORE, Callaway Golf prays:

1. That this Court enjoin Acushnet, its agents and employees, and any others acting

in concert with it, from infringing, inducing the infringement of, or contributing to the infringement of U.S. Patent Nos. 6,348,015, 6,478,692, 6,669,579, 6,685,576, and 6,949,032;

2. That this Court award Callaway Golf damages adequate to compensate for Acushnet's infringement;

3. That this Court award Callaway Golf treble damages as a result of Acushnet's willful infringement;

4. That this Court declare this case an exceptional case pursuant to 35 U.S.C. § 285;

5. That this Court award Callaway Golf its costs and attorneys' fees and such other relief as is just and proper.

JURY DEMAND

Callaway Golf demands trial by jury on all issues so triable.

FISH & RICHARDSON P.C.

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Exhibit A

US006348015B1

(12) **United States Patent**
Kosmatka(10) **Patent No.: US 6,348,015 B1**
(45) **Date of Patent: Feb. 19, 2002**(54) **GOLF CLUB HEAD HAVING A STRIKING
FACE WITH IMPROVED IMPACT
EFFICIENCY**(75) Inventor: **John B. Kosmatka**, Encinitas, CA (US)(73) Assignee: **Callaway Golf Company**, Carlsbad,
CA (US)(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.(21) Appl. No.: **09/525,216**(22) Filed: **Mar. 14, 2000**(51) **Int. Cl.⁷ A63B 53/04**(52) **U.S. Cl. 473/342; 473/329; 473/345;
473/349; 473/350**(58) **Field of Search 473/324, 332,
473/349, 350, 329, 342, 345, 346, 290,
291**

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Primary Examiner—Raleigh W. Chiu(74) *Attorney, Agent, or Firm*—Michael A. Catania(57) **ABSTRACT**

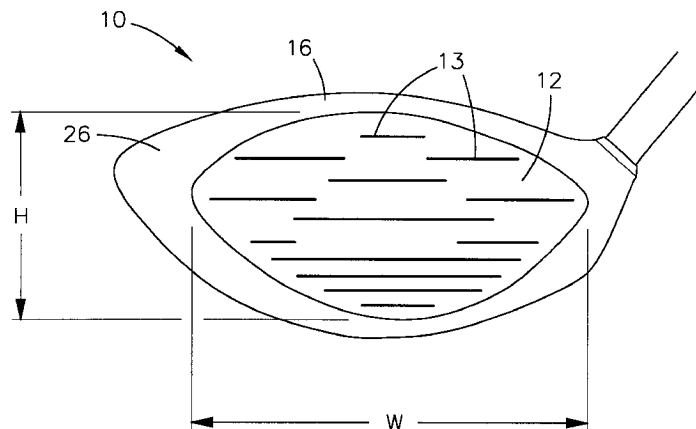
A compliant golf club head permits a more efficient impact between a golf ball and the golf club head. Material and geometry constraints of a striking plate of the golf club head can reduce energy losses caused by large strain and strain rate values of the golf ball, these constraints on the striking plate yield a measure of the impact efficiency of the golf club head. Designating a required natural frequency range of the striking plate provides improved impact efficiency between the golf ball the golf club head.

25 Claims, 7 Drawing Sheets

(56)

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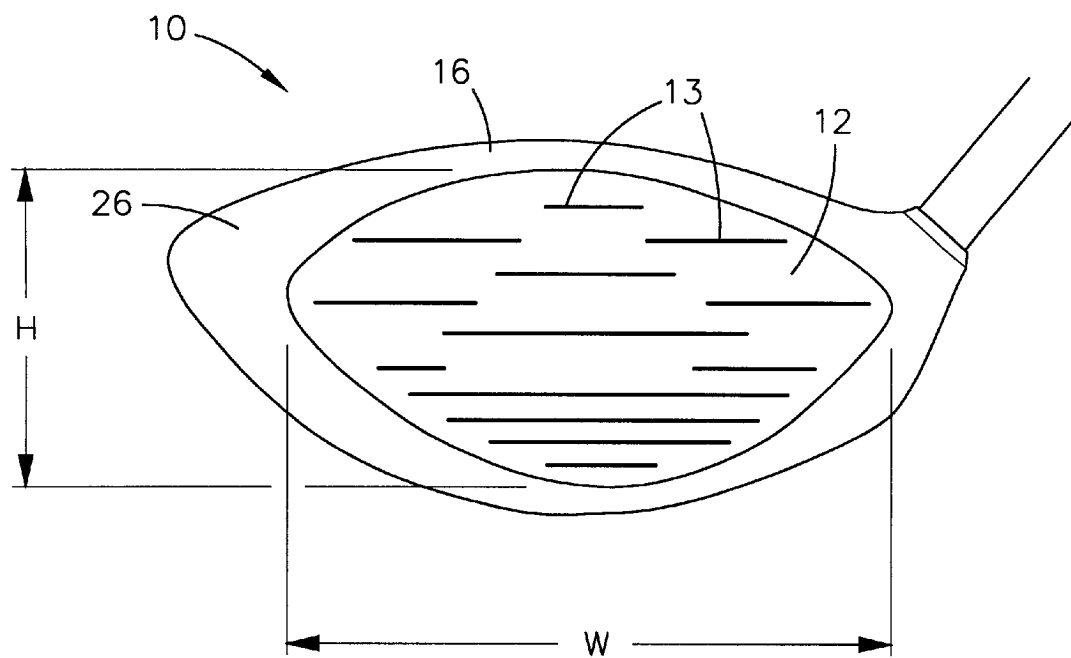
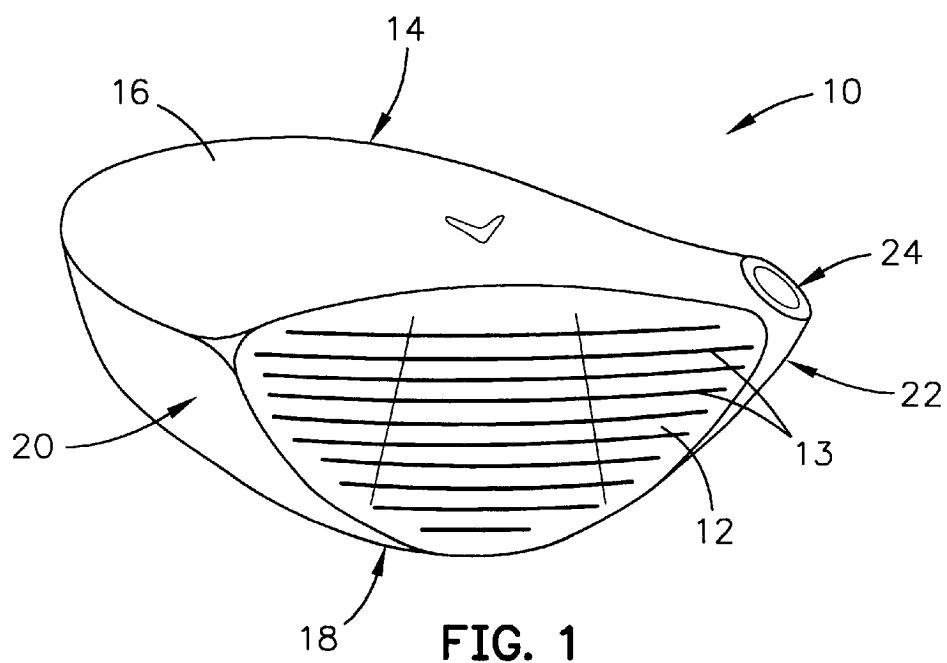


FIG. 2

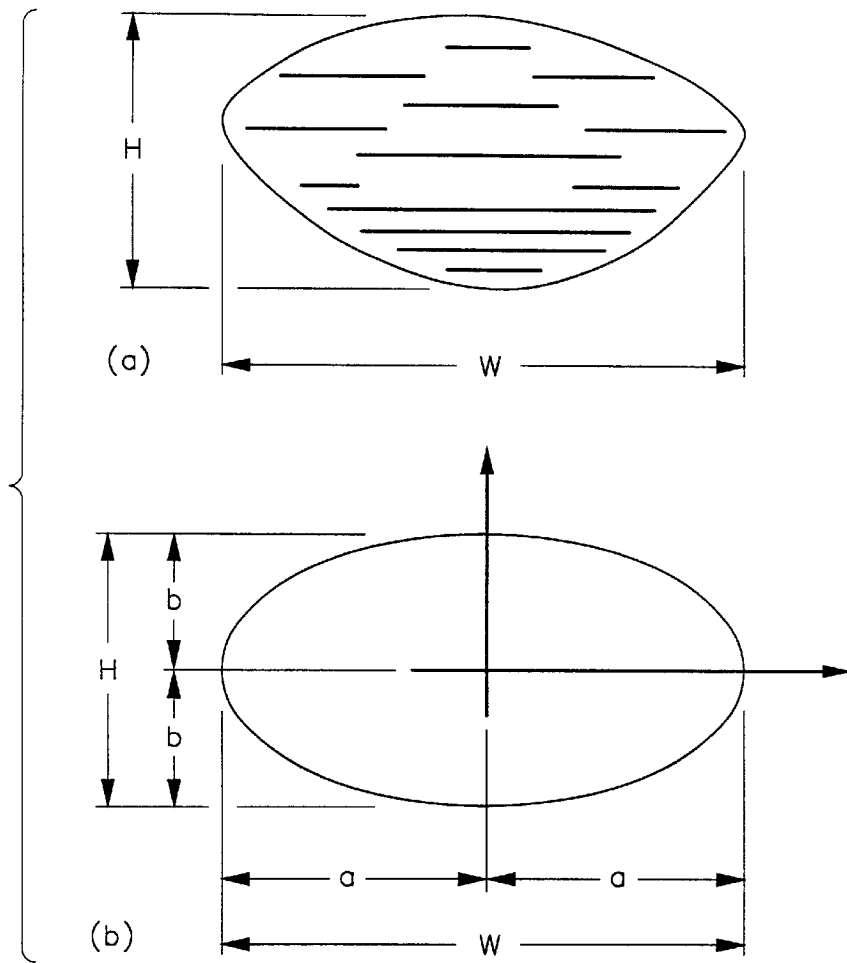


FIG. 3

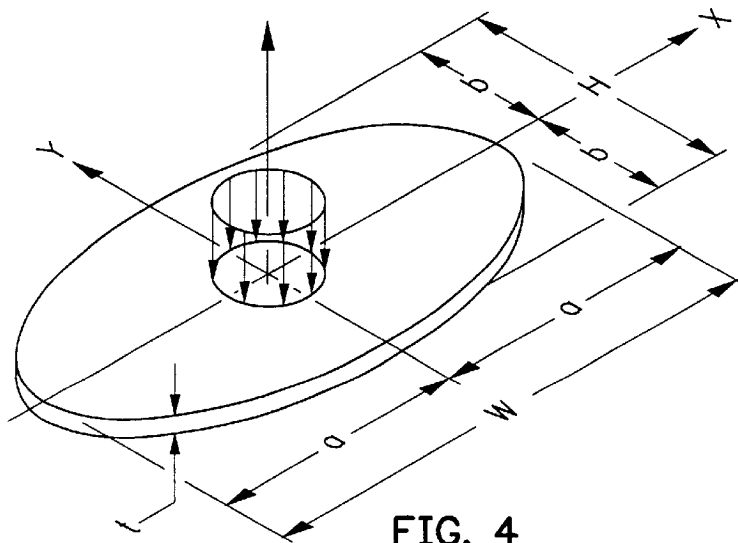


FIG. 4

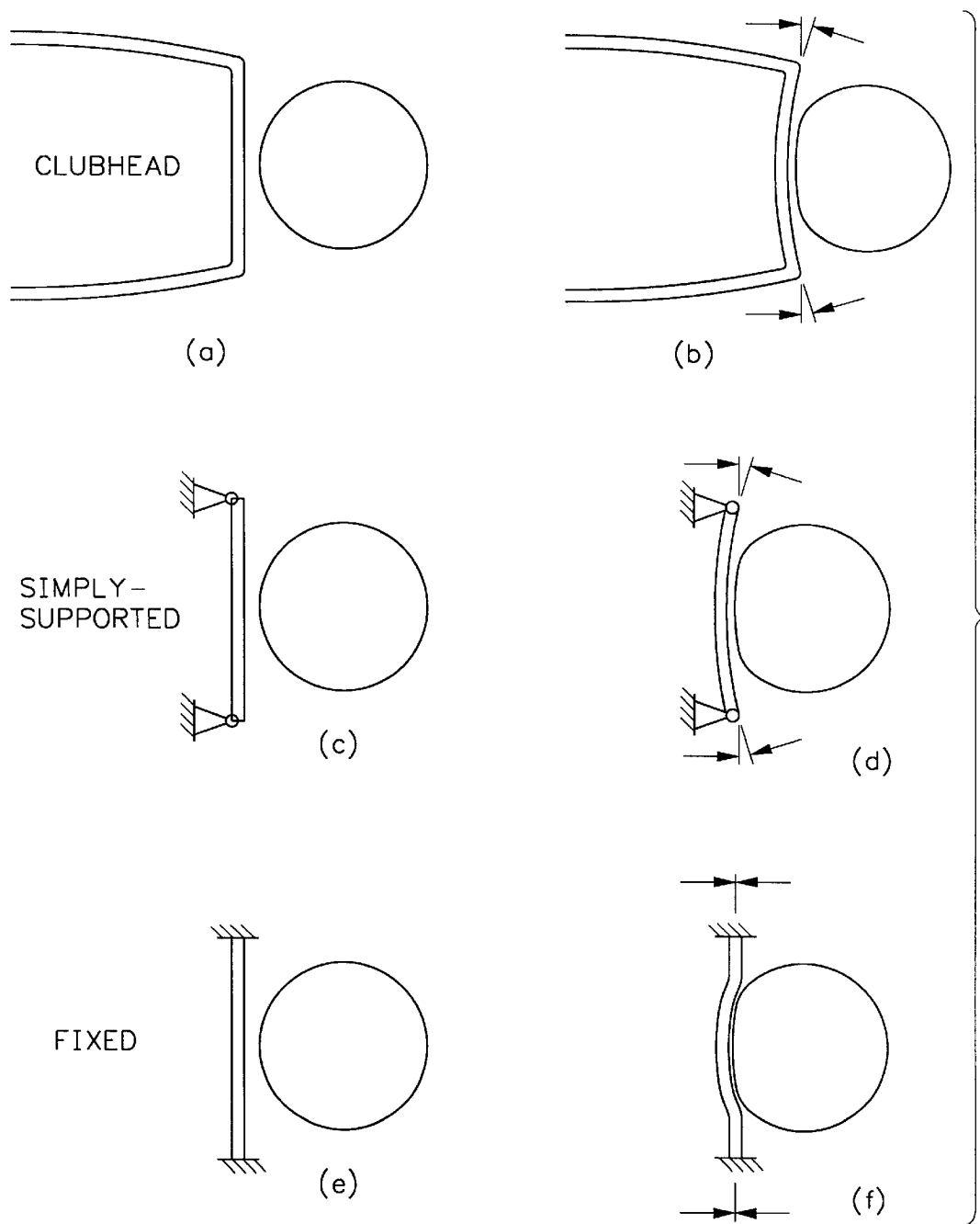


FIG. 5

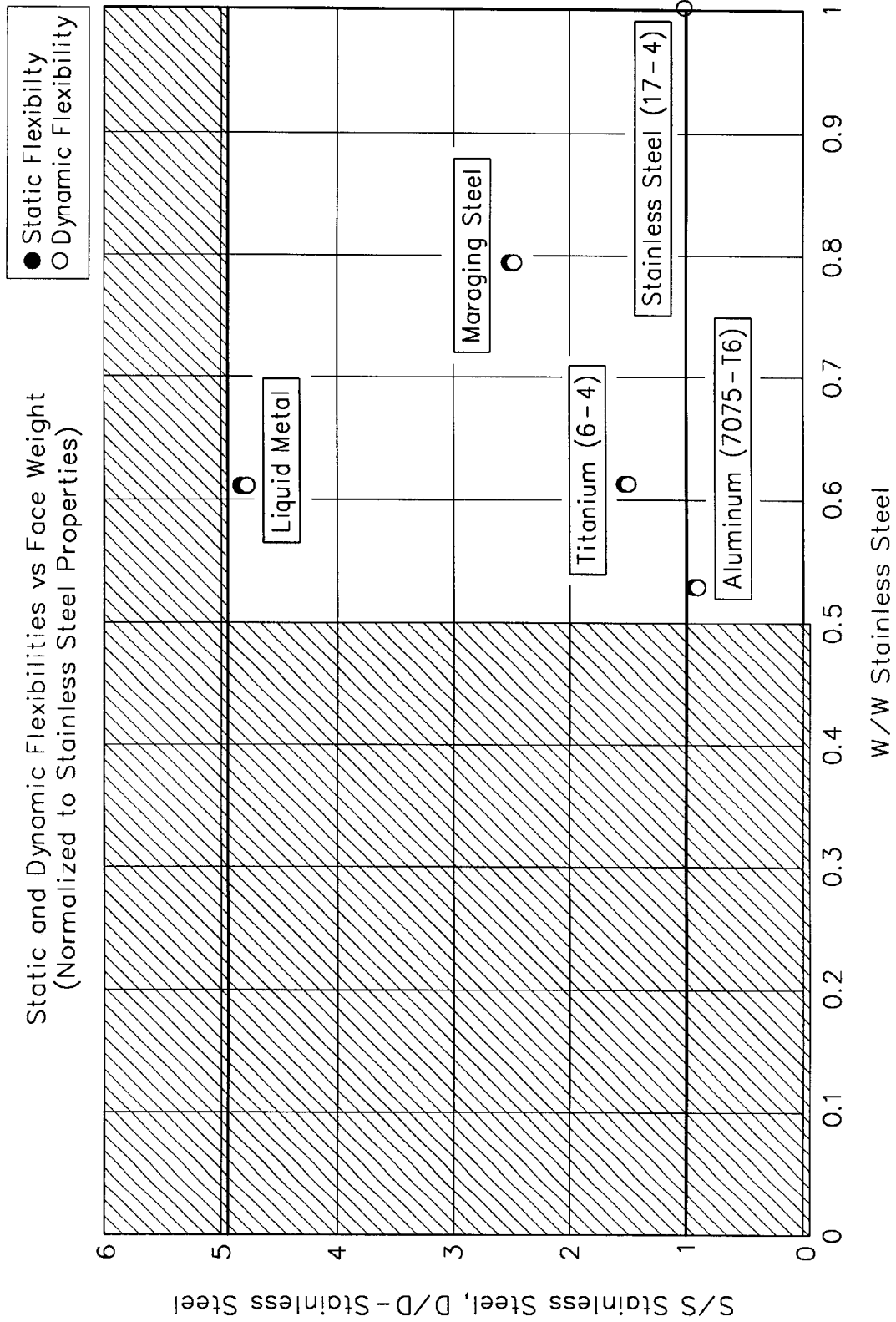


FIG. 6

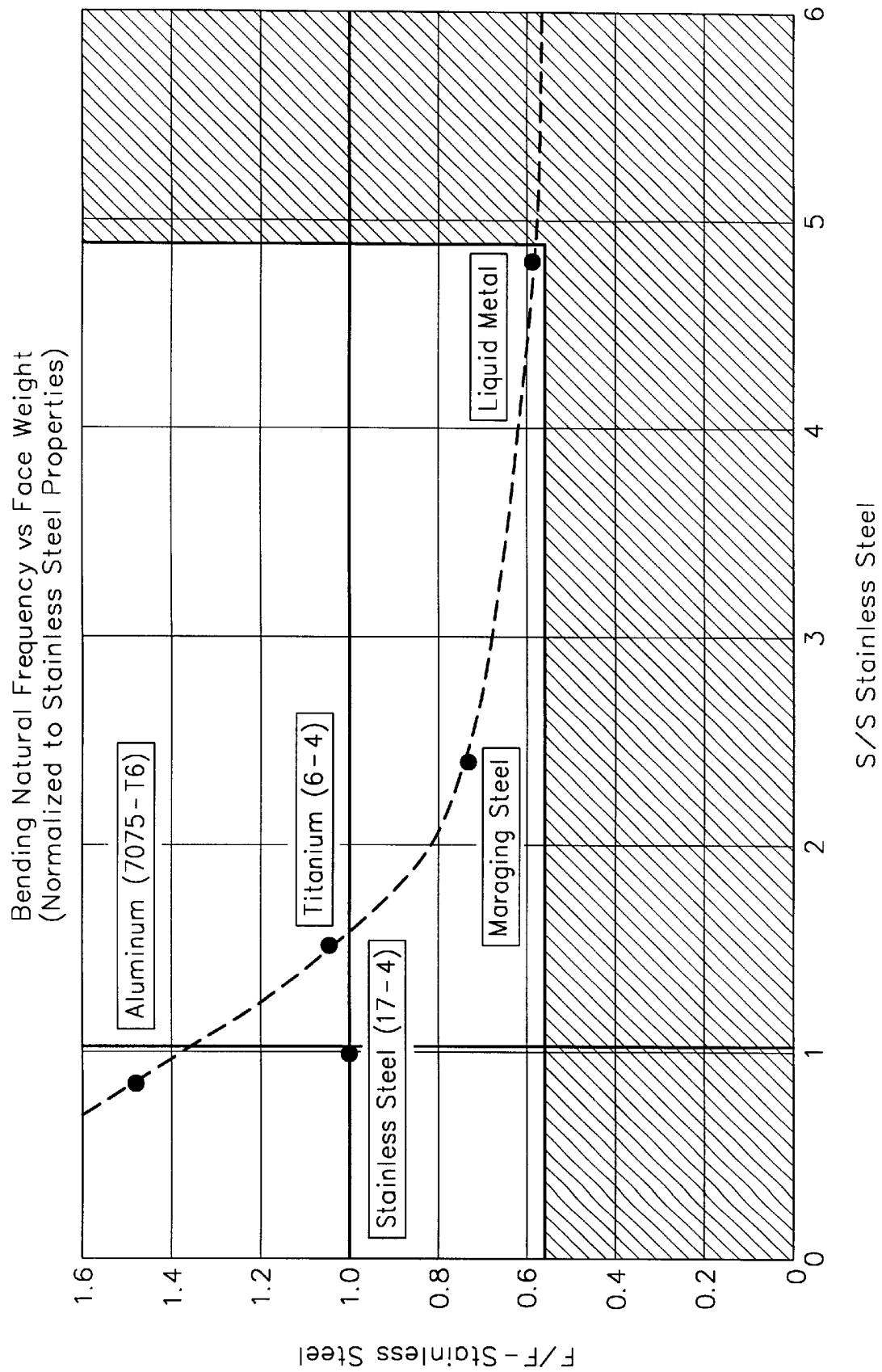


FIG. 7

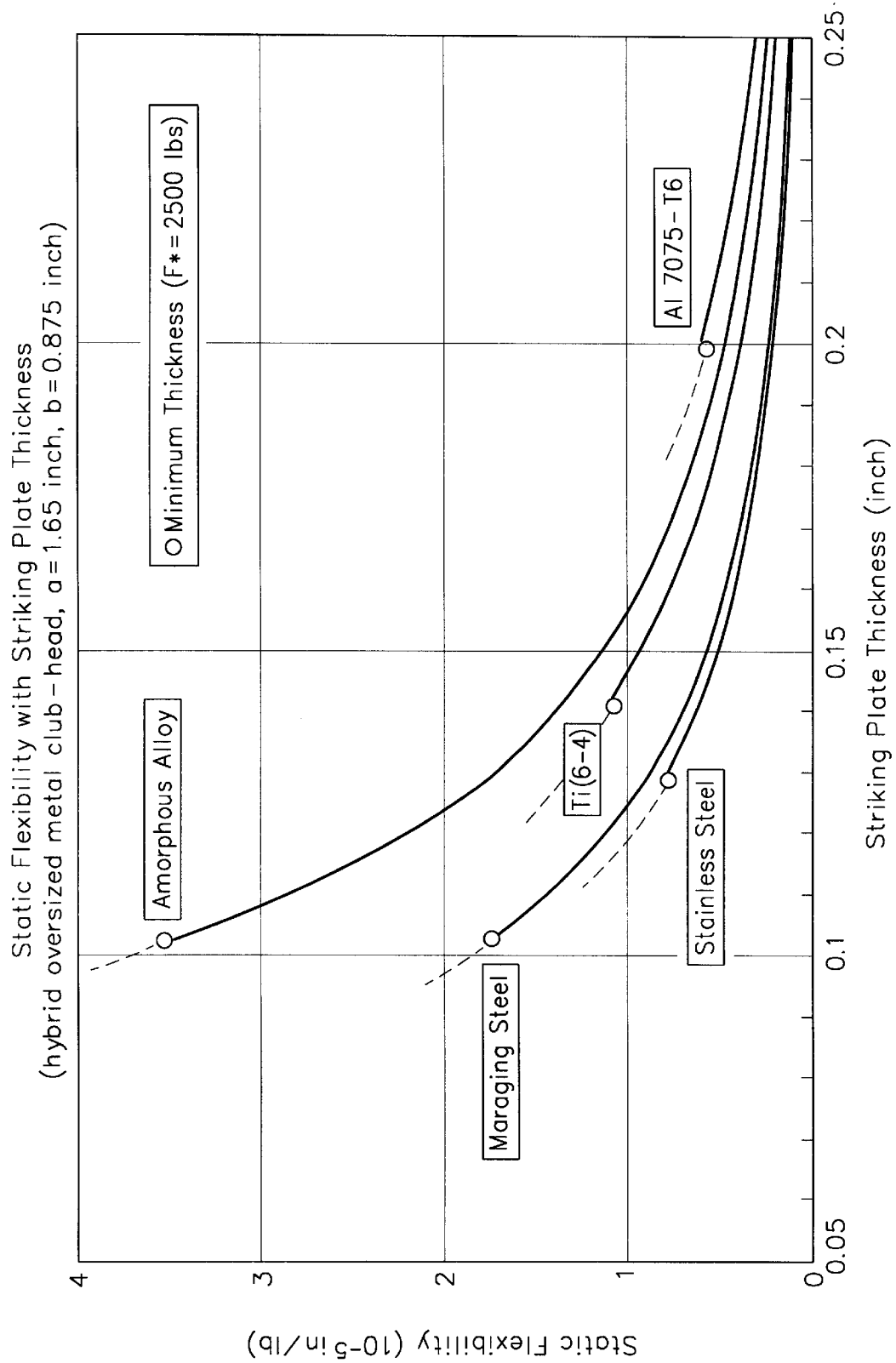
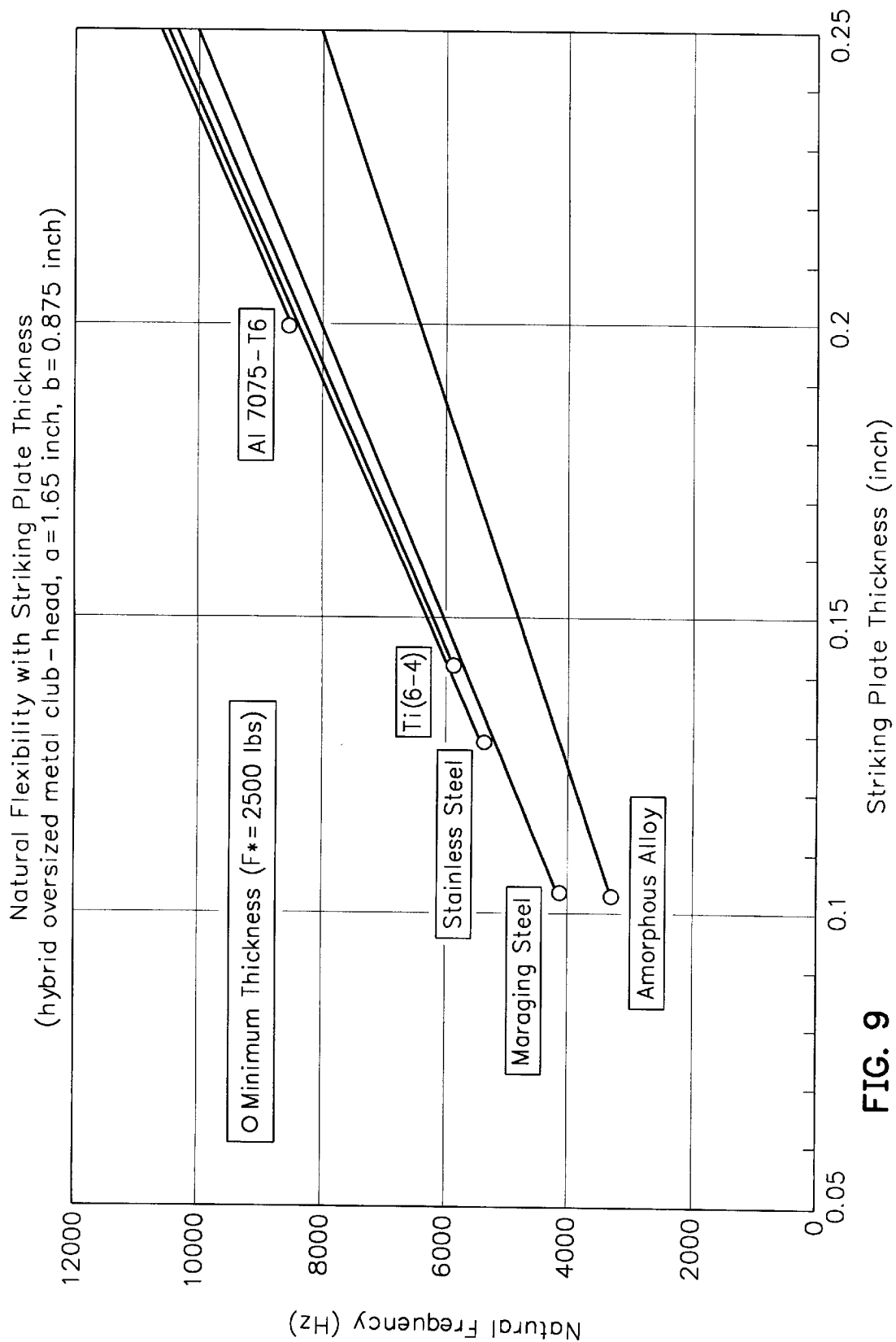


FIG. 8



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**GOLF CLUB HEAD HAVING A STRIKING
FACE WITH IMPROVED IMPACT
EFFICIENCY**

**CROSS REFERENCES TO RELATED
APPLICATIONS**

Not Applicable

**STATEMENT REGARDING FEDERALLY
SPONSORED RESEARCH OR DEVELOPMENT**

Not Applicable

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a golf club head. More specifically, the present invention relates to a face section of a golf club head to reduce energy losses when impacting a golf ball.

2. Description of the Related Art

Technical innovation in the material, construction and performance of golf clubs has resulted in a variety of new products. The advent of metals as a structural material has largely replaced natural wood for wood-type golf club heads, and is but one example of this technical innovation resulting in a major change in the golf industry. In conjunction with such major changes are smaller scale refinements to likewise achieve dramatic results in golf club performance. For example, the metals comprising the structural elements of a golf club head have distinct requirements according to location in the golf club head. A sole or bottom section of the golf club head should be capable of withstanding high frictional forces for contacting the ground. A crown or top section should be lightweight to maintain a low center of gravity. A front or face of the golf club head should exhibit high strength and durability to withstand repeated impact with a golf ball. While various metals and composites are known for use in the face, several problems arise from the use of existing materials.

Existing golf club face materials such as stainless steel exhibit desired high strength and durability but incur large energy losses during impact with the golf ball as a result of large ball deformations. An improvement in impact energy conservation, in conjunction with proper golf ball launch parameters, is a design goal for golf club manufacturers. The problem still exists of identifying a combination of material properties exhibiting improvements in conservation of impact energy during impact with the golf ball.

BRIEF SUMMARY OF THE INVENTION

When a golf club head strikes a golf ball, large impact forces are produced that load a face section, also called a striking plate, of the golf club head. Most of the energy is transferred from the golf club head to the golf ball; however, some energy is lost as a result of the impact. The present invention comprises a golf club striking plate material and geometry having a unique combination of material properties for improved energy efficiency during impact with the golf ball.

The golf ball is typically a core-shell arrangement composed of polymer cover materials, such as ionomers, surrounding a rubber-like core. The golf ball materials have stiffness properties defined as the storage and loss moduli for compression (E'_{ball} , E''_{ball}) and storage and loss moduli for shear (G'_{ball} , G''_{ball}) that are strain (or load), strain rate (or

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time rate of loading), input frequency, and temperature dependent. The compression loss factor (η_E) and shear loss factor (η_G) (damping or energy loss mechanisms), which are defined as the ratio of loss modulus to the storage modulus, are also strain, strain rate, input frequency, and temperature dependent. The golf ball loss factors, or damping level, is on the order of 10–100 times larger than the damping level of a metallic golf club striking plate. Thus, during impact most of the energy is lost as a result of the large deformations, typically 0.05 to 0.50 inches, and deformation rates of the golf ball as opposed to the small deformations of the metallic striking plate of the golf club head, typically 0.025 to 0.050 inches.

By allowing the golf club head to flex and “cradle” the golf ball during impact, the contact region as well as contact time between the golf ball and the striking plate of the golf club head are increased, thus reducing the magnitude of the internal golf ball stresses as well as the rate of the stress build-up. This results in smaller golf ball deformations and lowers deformation rates, both of which produce much lower energy losses in the golf ball during impact. The static flexibility is inversely proportional to the striking plate stiffness, while the dynamic flexibility is inversely proportional to square of the striking plate bending natural frequency. In other words, a decrease in plate stiffness will cause the static flexibility to increase, while doubling the plate bending natural frequency will reduce dynamic flexibility to a level $\frac{1}{4}$ of the original striking plate. Increasing the static or dynamic flexibility can be accomplished via several different configurations for the golf club head: altering geometry of the face section; altering attachment of the striking plate to the club-head body; reducing the thickness of the striking plate; or through the innovative use of new structural materials having reduced material stiffness and/or increased material density. Material strength of the striking plate of the golf club head in conjunction with impact load from contact with the golf ball determines the minimum required thickness for the face section. The greater the available material strength, the thinner the striking plate can be, and thus greater the flexibility. So the material properties that control static and dynamic flexibility are decreased compression stiffness, increased density, and increased strength. The present invention specifies which face materials and static/dynamic flexibilities provide improved energy conservation during impact of the golf club head and the golf ball. Materials used in the face section of the golf club head constitute an additional important factor in determining performance characteristics of coefficient of restitution (COR), launch angle, spin rate and durability.

One object of the present invention is to improve impact efficiency between a golf club head and the golf ball.

Another object is to designate a range of material properties to increase the static flexibility, otherwise described as reduced bending stiffness, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

Another object is to designate a range of material properties to increase the dynamic flexibility, otherwise described as reduced bending natural frequency, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

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A further object of the present invention is a wood-type golf club head having a face section of a first material and a body section of a second material.

Another object of the present invention is a wood-type golf club head having a face section of a metal material.

Another object of the present invention is a wood-type golf club head having a face section of a non-metal material.

Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is a perspective view of a golf club head of an embodiment of the present invention.

FIG. 2 is a front view of a golf club head showing a striking plate with a major cross-section dimensional width (W) and a minor cross-section dimensional height (H).

FIG. 3a shows a striking plate having an elliptical shape with a major and a minor cross-section dimensions (W) and (H), respectively, of an embodiment of the present invention.

FIG. 4 shows an elliptical plate with a pressure loading over a central circular region.

FIG. 5a shows the face section of the club head, of an embodiment of the present invention, prior to impact with the golf ball.

FIG. 5b shows deformation of the striking plate of the golf club head, of an embodiment of the present invention, during impact with the golf ball.

FIG. 5c shows an elliptical striking plate having a simply-supported edge constraint prior to impact with the golf ball.

FIG. 5d shows deformation of the elliptical striking plate of FIG. 5c during impact with the golf ball.

FIG. 5e shows an elliptical striking plate having a fixed edge constraint prior to impact with a golf ball.

FIG. 5f shows the elliptical striking plate of FIG. 5e during impact with the golf ball.

FIG. 6 is a plot of the normalized static and dynamic flexibility versus the face weight for a minimum weight design.

FIG. 7 is a plot of the bending natural frequency versus the static flexibility for a minimum thickness design.

FIG. 8 is a plot of the static flexibility versus striking plate thickness for a large club head utilizing five different materials for the golf club striking plate.

FIG. 9 is a plot of the natural frequency versus striking plate thickness for a large club head utilizing five different golf club striking plate materials.

DETAILED DESCRIPTION OF THE INVENTION

Like numbers are used throughout the detailed description to designate corresponding parts of a golf club head of the present invention.

As shown in FIG. 1 a wood-type golf club head 10 comprises a face section 12, a rear section 14, a top section 16, a bottom section 18, a toe section 20, a heel section 22 and a hosel inlet 24 to accept a golf shaft (not shown). The golf club head 10 is a unitary structure which may be composed of two or more elements joined together to form the golf club head 10. The face section 12, also called a

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striking plate, is an impact surface for contacting a golf ball (not shown). Structural material for the golf club head 10 can be selected from metals and non-metals, with a face material exhibiting a maximum limit for face stiffness and natural frequency being a preferred embodiment.

The present invention is directed at a golf club head 10 having a striking plate 12 that makes use of materials to increase striking plate flexibility so that during impact less energy is lost, thereby increasing the energy transfer to the golf ball. This increased energy transfer to the golf ball will result in greater impact efficiency. The striking plate 12 is generally composed of a single piece of metal or nonmetallic material and may have a plurality of score-lines 13 thereon. The striking plate 12 may be cast with a body 26, or it may be attached through bonding or welding to the body 26. See FIGS. 1 and 2.

For explanation purposes, the striking plate 12 is treated as an elliptical shaped cross section having a uniform thickness, denoted as "t" in FIG. 4, that is subjected to a distributed load over a small circular region at the center of the striking plate 12. See FIGS. 3 and 4. Those skilled in the pertinent art will recognize that striking plates having other shapes, nonuniform thickness distribution, and force locations are within the scope and spirit of the present invention. The overall cross-section width is given by (W=2a), the overall cross-section height (H=2b), and the striking plate aspect ratio is defined as ($\alpha=b/a$). The impact load, resulting from impact of the golf ball with the golf club head 10, is treated as force of magnitude (F), acting with a pressure (q) over a circular region of radius (r_c) in the center of the elliptical plate so that

$$F = \int_0^{2\pi} \int_0^{r_c} q r dr d\theta. \quad (I)$$

Like other striking plates of the prior art, the striking plate 12 of the present invention is positioned between the top section 16 and bottom section 18. During impact with the golf ball, the striking plate 12 will deflect depending upon the connection to the top section 16 and the bottom section 18, see FIGS. 5a-f. The two extreme limiting cases for all possible boundary attachment conditions are defined as "simply-supported" where the elliptical edge of the striking plate is constrained from translating but the edge is free to rotate, see FIGS. 5c and 5d, and "fixed" or "clamped" where the elliptical edge is fixed from both translating and rotating, see FIGS. 5e and 5f. The boundary attachment for the striking plate 12 to the body 26 of the club head 10 will fall between the two limiting cases since the top section 16 and bottom section 18 will provide some stiffening to the striking plate 12, but in general are very close to the simply supported condition. The calculated maximum stress in the striking plate as a result of the applied loading is

$$\sigma = \frac{3(1 + \nu)RF^*}{2\pi t^2} \quad (II)$$

where (F*) is the maximum load that includes the effects of design safety factors and the score-line 13 stress concentration factors, (t) is the plate thickness, (ν) is the material Poisson ratio, and (R) depends upon the plate geometry (a,b), load radius, material Poisson ratio, and edge support conditions. For golf club heads, the top section 16 and bottom section 18 provide some stiffening to the striking plate 12 edge, (R) will fall between the simply-supported

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edge and the fixed support, but for this invention it is very close to the simply-support edge condition;

$$R_{\text{simply-sup port}} = \ln\left(\frac{b}{r_o}\right) + \frac{\nu}{(1+\nu)}(6.57 - 2.57\alpha) \quad (\text{III.a,b})$$

$$R_{\text{fixed}} = \ln\left(\frac{2b}{r_o}\right) - .317\alpha - .376.$$

The minimum required thickness of the striking face based upon the applied loading is determined by setting the maximum stress to the allowable material yield stress (σ_{yield}) and solving;

$$t = \sqrt{\frac{3(1+\nu)RF^*}{2\pi\sigma_{\text{yield}}}}. \quad (\text{IV})$$

The minimum required striking plate thicknesses for two different materials (materials A and B) can be directly compared using Equation (IV), if one assumes that the impact forces, the plate geometry (W, H), and the edge boundary constraints are nearly the same. Writing the ratio of the minimum required thicknesses for two different materials is

$$\frac{t_A}{t_B} = \sqrt{\frac{(\sigma_{\text{yield-B}})(1+\nu_A)}{(\sigma_{\text{yield-A}})(1+\nu_B)}}, \quad (\text{V})$$

where (t_A) and (t_B) are the minimum required thicknesses for plates composed of materials A and B, respectively, and ($\sigma_{\text{yield-A}}$, ν_A) and ($\sigma_{\text{yield-B}}$, ν_B) are the material properties of A and B, respectively. A weight ratio comparison of two minimum thickness striking plates is equal to

$$\frac{W_A}{W_B} = \frac{\rho_A t_A \pi a b}{\rho_B t_B \pi a b} = \frac{\rho_A}{\rho_B} \sqrt{\frac{(\sigma_{\text{yield-B}})(1+\nu_A)}{(\sigma_{\text{yield-A}})(1+\nu_B)}}, \quad (\text{VI})$$

where (ρ_A) and (ρ_B) are the densities of material A and B, respectively, and these plates have identical geometry (W, H), boundary constraints, and are designed to withstand the same load (F^*).

Static Flexibility

The calculated striking plate static flexibility (S), which is the inverse of the plate stiffness, is defined as the calculated center displacement of the striking plate 12 divided by the plate force (F^*) and is equal to:

$$S = \frac{b^2}{E t^3} P, \quad (\text{VII})$$

where (b) is half the height of the striking plate 12, (E) is Young's modulus and (P) depends upon the geometry and the support conditions of the elliptical plate. For golf heads, (P) will fall between the simply-supported and fixed edge conditions, but for this invention it falls very close to the simply-supported edge condition;

$$P_{\text{simply-sup port}} = (0.76 - 0.18\alpha)$$

$$P_{\text{fixed}} = (0.326 - 0.104\alpha) \quad (\text{VIII.a,b})$$

Thus, increased striking plate flexibility can be accomplished by increasing the striking plate height (b), decreas-

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ing the Young's modulus (E), also described as material stiffness, or by reducing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV) into (VII), results in the static flexibility having a minimum allowable plate thickness;

$$S = \left[\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{3/2} \right] \left[P b^2 \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right], \quad (\text{IX})$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (P, R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are the same for two different designs (second bracketed term of Equation IX), then to maximize the static flexibility, one needs to select a material having the largest ratio of:

$$\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{3/2}. \quad (\text{X})$$

The static flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (IX) as a ratio

$$\frac{S_A}{S_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{\sigma_{\text{yield-A}}}{\sigma_{\text{yield-B}}} \right)^{3/2} \left(\frac{1+\nu_B}{1+\nu_A} \right)^{3/2}, \quad (\text{XI})$$

where (S_A) and (S_B) are the static flexibilities of a plate having a minimum plate thickness for materials A and B, respectively and (E_A) and (E_B) are the material stiffness for materials A and B, respectively.

Bending Natural Frequency

The calculated bending natural frequency (ω), or referred to simply as natural frequency, having units of cycles/second (Hz), for the elliptical striking plate is given by;

$$\omega(\text{Hz}) = \frac{\lambda t}{b^2} \sqrt{\frac{Eg}{\rho(1-\nu^2)}} \quad (\text{XII})$$

where (ν) is the material Poisson ratio, (b) is half the height of the striking plate 12, (ρ) is the material weight density, (g) is the gravitational constant (32.2 ft/sec²), and (λ) depends upon the geometry and the support conditions of the elliptical plate, as well as the desired vibration mode. For golf club heads, (λ) will fall between the two limiting edge support values, simply-support and fixed, but for this invention it is very close to the simply-support condition;

$$\lambda_{\text{simply-sup port}} = 0.124 \sqrt{1 + 0.21\alpha + 2.37\alpha^2 - 3.03\alpha^3 + 2.7\alpha^4}$$

$$\lambda_{\text{fixed}} = 0.2877 \sqrt{1 + \frac{2}{3}\alpha^2 + \alpha^4}. \quad (\text{XIII.a,b})$$

The bending natural frequency can be minimized by increasing the striking plate 12 height (2b) or aspect ratio (α), increasing the material density (ρ), decreasing the material stiffness (E), or decreasing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation

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(IV) into (XII), results in the natural frequency having a minimum allowable plate thickness;

$$\omega = \left[\sqrt{\frac{E}{\sigma_{yield}\rho(1-\nu)}} \right] \left[\frac{\lambda}{b^2} \sqrt{\frac{3gRF^*}{2\pi}} \right] \quad (XIV)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are the fixed (second bracketed term of Equation XIV), then to minimize the natural frequency, one needs to select a material having the smallest of:

$$\frac{E}{\sigma_{yield}\rho(1-\nu)} \quad (XV)$$

The natural frequency of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XIV) as a ratio

$$\frac{\omega_A}{\omega_B} = \sqrt{\left(\frac{E_A}{E_B} \right) \left(\frac{\sigma_{yield-B}}{\sigma_{yield-A}} \right) \left(\frac{\rho_B}{\rho_A} \right) \left(\frac{1-\nu_B}{1-\nu_A} \right)}, \quad (XVI)$$

where (ω_A) and (ω_B) are the natural frequencies of a striking plate having a minimum plate thickness for materials A and B.

A golf club head has a large number of natural frequencies, where some involve the vibratory motion that characterize the striking plate, others involve motion that characterize the top plate or bottom plate, and still others involve the combined motion of the striking plate and other parts of the club head. The natural frequencies that are of concern in the present invention involve the full or partial vibratory motion of the striking plate. Thus, to experimentally measure these frequencies, one needs to excite the striking plate as well as record its response. A noncontacting excitation and response system is preferred to insure that added mass or stiffness effects do not artificially alter the results. In our experimental studies, the striking plate was excited using either an impact hammer (PCB Inc. of Buffalo, N.Y., model 068, series 291; or Kistler Instrument Corp. of Amherst, N.Y., model 9722A500) or an acoustical funnel-cone speaker, where the speaker is driven with broad-band "white" random noise between 1000–10,000 Hz. The velocity time history (response) is measured using a laser velocimeter (Polytec PI GmbH of Waldbronn, Germany, model OFV-303 or PSV-300; or Ometron Inc. of London, England, model VPI-4000). The recorded excitation and response time histories are processed using a two-channel spectrum analyzer (Hewlett Packard of Palo Alto, Calif.) to determine the frequency content of the response signal divided by the excitation signal. The spectrum analyzer has input/output windowing features and anti-aliasing filters to eliminate processing errors. The test is repeated a minimum of 10 times and the data is averaged to minimize the effects of uncorrelated noise. Thus the coherence was found to be greater than 0.98 at all measured natural frequencies. The tests are repeated using numerous excitation and response locations on the striking plate to insure that the lowest striking plate dominated natural frequencies are recorded.

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Dynamic Flexibility

The dynamic flexibility (D) for the striking plate is given by

$$D = \frac{1}{m_e(2\pi\omega)^2}, \quad (XVII)$$

where, (ω) is the striking plate natural frequency, and (m_e) is the effective face mass that contributes to the dynamic response during impact:

$$m_e = \beta \frac{\rho}{g} \pi t a b = \beta \frac{\rho}{g} \pi t \frac{b^2}{\alpha}. \quad (XVIII)$$

Here (β) is defined between (0) and (1), where (0) is associated with no face mass contributing to the dynamic response and (1) having all of the face mass contributing to the response. For golf clubs, ($0.15 < \beta < 0.35$). Writing the dynamic flexibility by substituting Equations (XIV) and (XVIII) into (XVII):

$$D = \frac{b^2}{E t^3} \left(\frac{\alpha(1-\nu^2)}{4\beta\pi^3\lambda^2} \right). \quad (XIX)$$

The striking plate dynamic flexibility can be increased by enlarging the plate depth (b) or aspect ratio (α), decreasing the material stiffness (E), or decreasing the plate thickness (t). Clearly the greatest increase in (D) can be found by changing the thickness (t), followed by changing the face height (2b). But, the plate thickness can only be reduced up to the allowable value of Equation (IV). Thus, the maximum dynamic flexibility (D) for a given plate geometry and applied load is calculated by substituting the minimum allowable thickness Equation (IV) into (XIX):

$$D = \left[\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \right] \left[\left(\frac{\alpha b^2}{4\beta\pi^3\lambda^2} \right) \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right] \quad (XX)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (λ , R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are constant (second bracketed term of Equation XX), then to maximize the dynamic flexibility (D), one needs to select a material having the largest ratio of:

$$\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \quad (XXI)$$

The dynamic flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XX) as a ratio

$$\frac{D_A}{D_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{1-\nu_A^2}{1-\nu_B^2} \right) \left(\frac{\sigma_{yield-A}}{\sigma_{yield-B}} \right)^{3/2} \left(\frac{1+\nu_A}{1+\nu_B} \right)^{3/2}, \quad (XXII)$$

where (D_A) and (D_B) are the maximum dynamic flexibilities of a plate having a minimum plate thickness for materials A and B, respectively.

For wood-type golf clubs the following geometry and force properties are typical (a=1.4–1.65 inch, b=0.7–1.0

inch, $t=0.14\text{--}0.25$ inch, $F^*=2000\text{--}15,000$ lbs). In Table 1, current metal golf club head material properties are given along with five different golf club head property ratios. These five different ratios include: minimum required striking plate thickness (Eq. V), resulting striking plate weight (Eq. VI), static flexibility (Eq. XI), bending natural frequency (Eq. XVI), and dynamic flexibility (Eq. XXII), where the baseline (B) material is taken as (17-4) Stainless Steel. These ratios provide a comparison of striking plates that have identical elliptical geometry, edge attachment, and load capacity, but are composed of different materials and thus will have different minimum striking plate thicknesses. A normalized comparison of the static flexibility and dynamic flexibility to face weight is presented in FIG. 6, where all results are normalized to an equivalent (17-4) Stainless Steel striking plate. In FIG. 6. It is clear that the amorphous alloy striking plate and maraging striking plate offer (4.8) and (2.5) times more flexibility and lower face weight than stainless steel as a result of their high strength, while the titanium alloy striking plate offers 50% more flexibility and lower face weight as a result of significantly lower modulus, but that the aluminum alloy striking plate results in lower flexibility as a result of its lower strength. These increases in flexibility lead to reduced impact energy losses, which in turn lead to greater golf ball flight velocities. In FIG. 7, a comparison of normalized face natural fre-

the maraging steel and amorphous alloy have a striking plate thickness of less than 0.100 inches, and more preferably between 0.100 and 0.070 inches. The Aluminum 7075-T6 striking plate is thickest because of its low strength, but it is the lightest as a result of its low density. In a preferred embodiment the striking plate of aluminum alloy has a maximum thickness of less than 0.200 inches, and more preferably between 0.200 and 0.070 inches. The striking plates composed of an amorphous alloy, Maraging 280 steel, and the 6-4 Titanium all have static and dynamic flexibilities much greater than the 17-4 Stainless Steel striking plate (480%, 240% and 150%), while the aluminum alloy striking plate has a 12% lower flexibility as a result of its large thickness. Finally, the striking plates composed of amorphous alloy and maraging steel have bending natural frequencies which are 41% and 27% lower, respectively, than the 17-4 Stainless Steel striking plate, whereas the titanium alloy striking plate is nearly the same as the stainless steel, while the aluminum alloy striking plate is 50% greater as a result of an increased thickness and low density.

It should be further pointed out, that most golf club designers use the striking plate weight savings to further increase the size of the striking plate (i.e. oversize titanium drivers) and thus further increase its static and dynamic flexibility.

TABLE 1

Typical Material Properties used in Golf Club Faces and Comparison Ratios									
Material (i)	E 10^6 lb/in^2	ν	σ_{yield} 10^3 lb/in^2	ρ lb/in^3	t_i/t_{steel}	W_i/W_{steel}	S_i/S_{steel}	$\omega_i/\omega_{\text{steel}}$	D_i/D_{steel}
Stainless Steel(17-4)	29.0	.27	150	.276	1.00	1.00	1.00	1.00	1.00
Aluminum (7075-T6)	10.4	.33	73	.101	1.47	0.54	0.88	1.48	0.85
Titanium (Ti 6-4)	16.0	.31	138	.160	1.06	0.61	1.53	1.05	1.49
Maraging 280 Steel	26.5	.31	262	.285	0.77	0.79	2.41	0.73	2.35
Amorphous Alloy	13.3	.30	260	.220	0.77	0.61	4.80	0.59	4.22

quency versus static flexibility is presented, where a correlation exists between measured natural frequency and static flexibility, and thus natural frequency can be used as a simple nondestructive measurement technique for assessing the magnitude of the static and dynamic flexibility. It is observed that the amorphous alloy and maraging steel striking plates have a lower natural frequency and greater flexibility than other materials in FIG. 7 because of their high strength and density. The titanium alloy striking plate and aluminum alloy striking plate have natural frequencies higher than all the other materials in FIG. 7 because of their low density.

A detailed inspection of Table 1 reveals that striking plates composed of Maraging 280 steel or the amorphous alloy are 23% thinner than the 17-4 Stainless Steel striking plate, which is a direct result of higher strength of these materials. In a preferred embodiment the striking plate of stainless steel has a maximum thickness of less than 0.130 inches, and more preferably between 0.130 and 0.070 inches, while both

As a second example, consider a very large oversized driver head similar to a Callaway Golf® Biggest Big Bertha driver that is fabricated with different material striking plates. The geometry values are defined as ($a=1.65$ inch, $b=0.875$ inch, $\alpha=0.530$). In order to produce striking plate flexibility levels greater than found in any current club-head: (1) the striking plate has no scorelines, thus ($F^*=2500$ lbs) with a radius ($r_o=0.50$ inch), and (2) the edge attachment condition is nearly simply-supported so that ($P=0.664$, $\lambda=0.1538$). Constructing the striking plate out of Titanium (Ti 6-4), leads to ($R=1.792$) and a minimum required face thickness of ($t=0.143$ inch). Including score-line stress concentration factors will simply increase (F^*), thus increasing the required face thickness (t) and bending natural frequency, and decreasing the flexibility. The calculated weight is ($W=0.103$ lb), the static flexibility is ($S=1.10\times 10^{-5}$ in/lb), the natural frequency ($\omega=5920$ Hz), and the dynamic flexibility ($D=1.08\times 10^{-5}$ in/lb), where it was assumed ($\beta=0.25$). The calculated head natural frequency of 5920 Hz

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is within 2% of the experimentally measured value of 6040 Hz on an actual experimental hybrid golf club head. The maximum displacement of the striking plate is found by multiplying the static flexibility and the effective force (F*), thus ($\Delta=0.0275$ inch). Hybrid golf club heads having different material striking face plates are presented in Table 2, where the striking plates have minimum allowable face thicknesses. In FIGS. 8 and 9, the variation of the static flexibility and natural frequency with striking plate thickness is presented for the five different metals, where the symbol (o) is used to represent the minimum allowable thickness for a assumed applied load (F*=2500 lbs). Clearly, if the applied load were increased then the minimum allowable thicknesses would increase, where the symbols would just move to the right along the appropriate curve. Thus lowering the flexibility and increasing the natural frequency. Moreover, if

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preferred embodiment the natural frequency is between 8500 Hz and 2800 Hz. For the titanium alloy striking plate 12, the natural frequency is below 5900 Hz, and in a more preferred embodiment the natural frequency is between 5900 Hz and 2800 Hz. For the stainless steel striking plate 12, the natural frequency is below 5400 Hz, and in a more preferred embodiment the natural frequency is between 5400 Hz and 2800 Hz. For the maraging steel striking plate 12, the natural frequency is below 6000 Hz, and in a more preferred embodiment the natural frequency is between 6000 Hz and 2800 Hz. For the amorphous alloy striking plate 12, the natural frequency is below 5500 Hz, and in a more preferred embodiment the natural frequency is between 5500 Hz and 2800 Hz.

TABLE 2

Calculated Striking Plate Properties for a Hybrid Oversized Driver Golf Club Head without scorelines (a = 1.65", b = .875", α = .530, F* = 2500 lb, r_0 = 0.5", P = 0.664, λ = .154, β = 0.25).											
Material (i)	E 10 ⁶ lb/in ²	ν	σ_{yield} 10 ³ lb/in ²	ρ lb/in ³	R	T Inch	W lb	S 10 ⁻⁵ in/lb	Δ inch	ω (Hz)	D 10 ⁻⁵ in/lb
Stainless Steel(17-4)	29.0	.27	150	.276	1.67	.130	.162	.803	.020	5458	.809
Aluminum (7075-T6)	10.4	.33	73	.101	1.85	.200	.092	.605	.015	8520	.586
Titanium (Ti 6-4)	16.0	.31	138	.160	1.79	.142	.103	1.10	.027	5920	1.08
Maraging 280 Steel	26.5	.31	262	.285	1.79	.103	.134	1.74	.043	4143	1.71
Amorphous Alloy	13.3	.30	260	.220	1.76	.102	.102	3.55	.089	3301	3.51

a higher strength version of an alloy were used, then the symbol would follow the curve to the left and thus increase the flexibility and lower natural frequency. It is observed that the greatest flexibility occurs for maraging steel and the amorphous alloy, which has the thinnest striking plates and lowest natural frequencies.

It is known through experimental testing, that currently available driver golf club heads have striking-face natural frequencies greater than 4500 Hz. Moreover, the only commercially available golf club head with an amorphous alloy striking plate (commercial name: Liquid Metal™) has a fundamental striking plate natural frequency of 5850 Hz. Thus, the striking plates on these club heads are not optimized for maximum flexibility. They do not have a minimum thickness striking plate, a large aspect ratio, or an edge support that simulates the simply supported constraint. From Equation XVII, the dynamic flexibility is inversely proportional to the square of the natural frequency, thus these heads have a flexibility that is much lower and a face thickness that is much greater than the optimized minimum values presented in the previous example (i.e. their values on FIGS. 8 and 9 would be to the far right of the minimum allowable thickness). In a preferred embodiment of the present invention, the material of striking plate 12 has a natural frequency of less than 4500 Hz, in a more preferred embodiment the striking plate 12 natural frequency is between 4500 Hz and 2800 Hz. For the aluminum alloy striking plate 12, the natural frequency is below 8500 Hz, and in a more

Although the above description is for wood-type golf club heads having an elliptical face section, the present invention is not limited to such an embodiment. Also included within the bounds of the present invention are iron type golf club heads and golf club heads with α values approaching 1.0.

From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

I claim as my invention:

1. A golf club head comprising:

a body;

a striking plate connected to the body,

the striking plate composed of a first material, and having a natural frequency of less than 4500 Hz and greater than 2800 Hz.

2. The golf club head of claim 1 wherein the first material is a metal selected from the group consisting of stainless steel, maraging steel, amorphous alloy, titanium alloy and aluminum alloy.

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3. A golf club head comprising:
 a body;
 a striking plate connected to the body,
 the striking plate composed of a first material, and
 having a natural frequency less than 4000 Hz and
 greater than 2800 Hz. 5
4. A golf club head comprising:
 a body;
 a striking plate connected to the body,
 the striking plate composed of a first material, and
 having a natural frequency less than 3300 Hz and
 greater than 2800 Hz. 10
5. A golf club head comprising:
 a body composed of a first material, the body having a top 15
 region, a bottom region, a rear region and an open front;
 a striking plate composed of a second material and having
 a natural frequency less than 8500 Hz and greater than
 2800 Hz, and
 the striking plate disposed in the open front of the body. 20
6. The golf club head of claim 5, wherein the second
 material is aluminum alloy.
7. The golf club head of claim 6, wherein the striking plate
 has a maximum thickness of less than 0.200 inches.
8. The golf club head of claim 7, wherein the maximum 25
 thickness of the striking plate is less than 0.200 inches and
 greater than 0.070 inches.
9. The golf club head of claim 5, wherein the second
 material is titanium alloy having a natural frequency less
 than 5900 Hz and greater than 2800 Hz.
10. The golf club head of claim 9, wherein the striking
 plate has a maximum thickness of less than 0.140 inches.
11. The golf club head of claim 10, wherein the maximum
 thickness of the striking plate is less than 0.140 inches and
 greater than 0.070 inches. 30
12. The golf club head of claim 5, wherein the second
 material is stainless steel having a natural frequency less
 than 5400 Hz and greater than 2800 Hz.
13. The golf club head of claim 12, wherein the striking
 plate has a maximum thickness of less than 0.130 inches. 35

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14. The golf club head of claim 13, wherein the maximum
 thickness of the striking plate is less than 0.130 inches and
 greater than 0.070 inches.
15. The golf club head of claim 5, wherein the second
 material is maraging steel having a natural frequency less
 than 6000 Hz and greater than 2800 Hz.
16. The golf club head of claim 15, wherein the striking
 plate has a maximum thickness of less than 0.100 inches.
17. The golf club head of claim 16, wherein the maximum
 thickness of the striking plate is less than 0.100 inches and
 greater than 0.070 inches. 10
18. The golf club head of claim 5, wherein the second
 material is amorphous alloy having a natural frequency less
 than 5500 Hz and greater than 2800 Hz.
19. The golf club head of claim 18, wherein the striking
 plate has a maximum thickness of less than 0.100 inches.
20. The golf club head of claim 19, wherein the maximum
 thickness of the striking plate is less than 0.100 inches and
 greater than 0.070 inches.
21. A golf club head comprising:
 a body composed of a first material, the body having a top
 region, a bottom region, a rear region and an open front;
 a striking plate composed of a metal material and having
 a natural frequency less than 8500 Hz and greater than
 2800 Hz, a maximum thickness of the striking plate is
 less than 0.200 inches and greater than 0.070 inches,
 and
 the striking plate disposed in the open front of the body.
22. The golf club head of claim 21 wherein the metal
 material is selected from the group consisting of aluminum
 alloy, titanium alloy, stainless steel, maraging steel and
 amorphous alloy. 30
23. The golf club head of claim 21 wherein the natural
 frequency is less than 4500 Hz and greater than 2800 Hz.
24. The golf club head of claim 23 wherein the natural
 frequency is less than 4000 Hz and greater than 2800 Hz. 35
25. The golf club head of claim 24 wherein the natural
 frequency is less than 3300 Hz and greater than 2800 Hz.

* * * * *

Exhibit B

US006478692B2

(12) **United States Patent**
Kosmatka

(10) **Patent No.:** **US 6,478,692 B2**
(45) **Date of Patent:** ***Nov. 12, 2002**

(54) **GOLF CLUB HEAD HAVING A STRIKING FACE WITH IMPROVED IMPACT EFFICIENCY**

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(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2 days.

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(51) Int. Cl.⁷ **A63B 53/04**

(52) U.S. Cl. **473/342; 473/329; 473/345; 473/349; 473/350**

(58) Field of Search **473/32, 332, 349, 473/350, 379, 342, 345, 346, 290, 291**

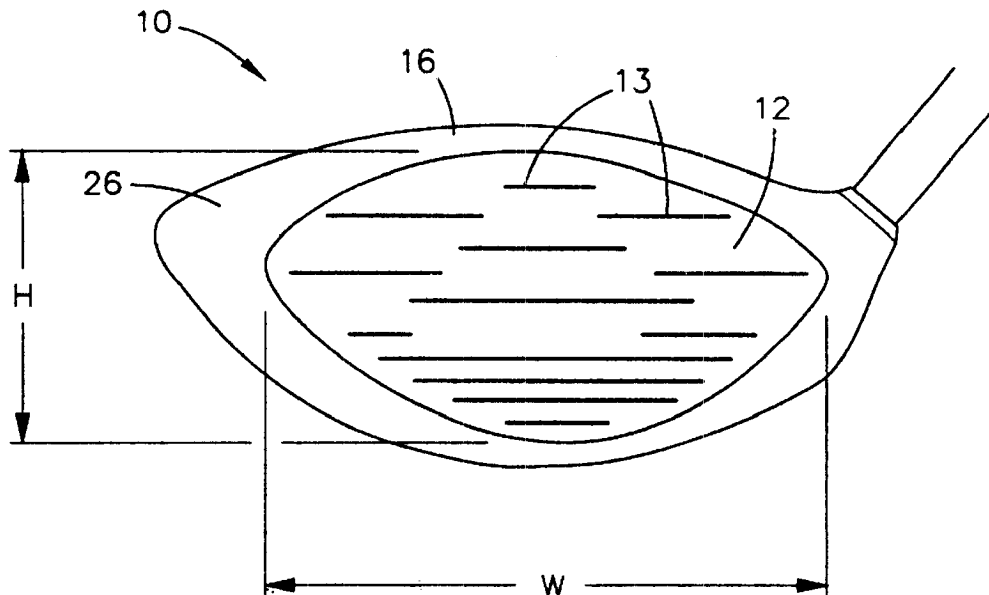
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(57) **ABSTRACT**

A compliant golf club head permits a more efficient impact between a golf ball and the golf club head. Material and geometry constraints of a striking plate of the golf club head can reduce energy losses caused by large strain and strain rate values of the golf ball, these constraints on the striking plate yield a measure of the impact efficiency of the golf club head. Designating a required natural frequency range of the striking plate provides improved impact efficiency between the golf ball the golf club head.

12 Claims, 7 Drawing Sheets



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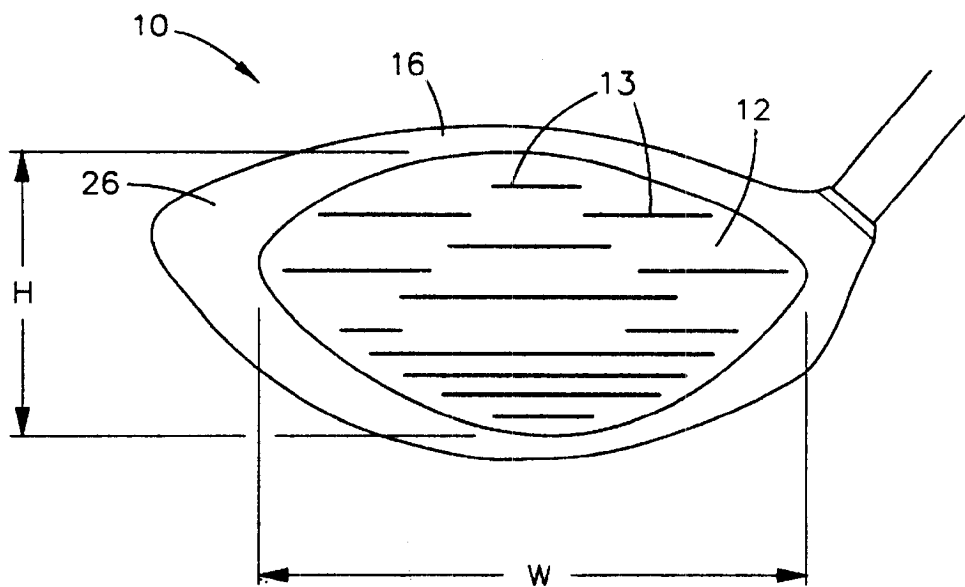
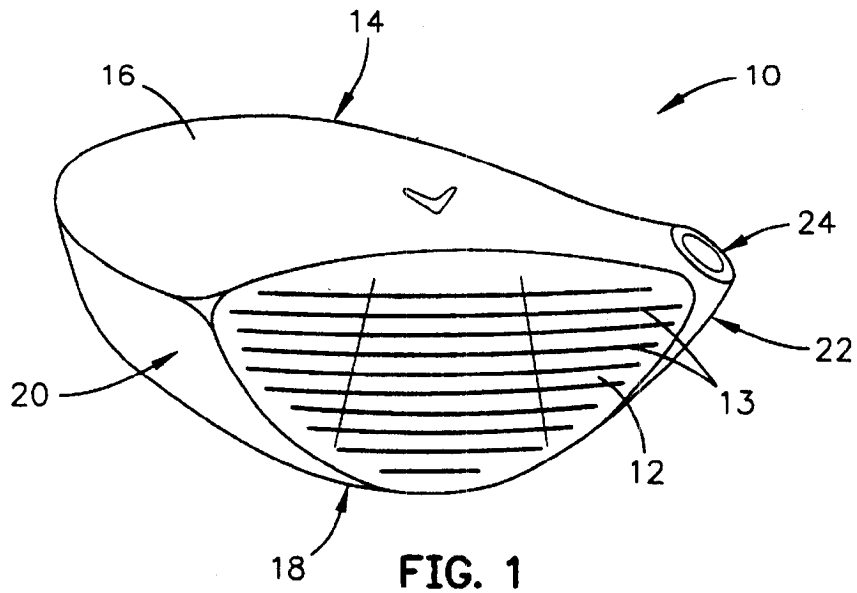


FIG. 2

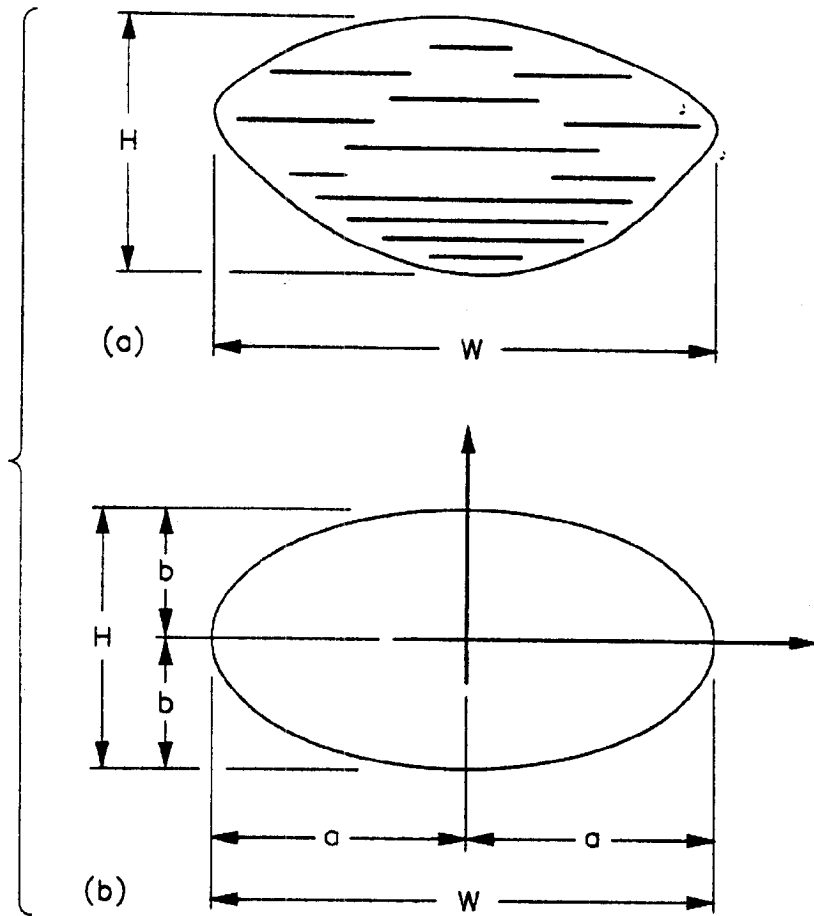


FIG. 3

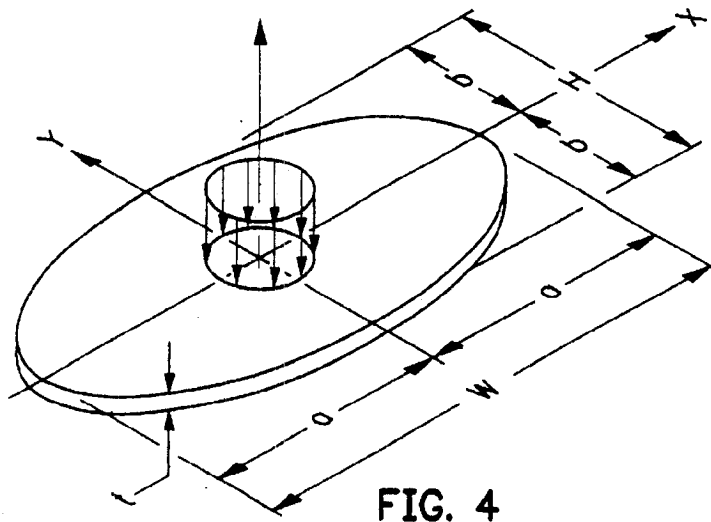


FIG. 4

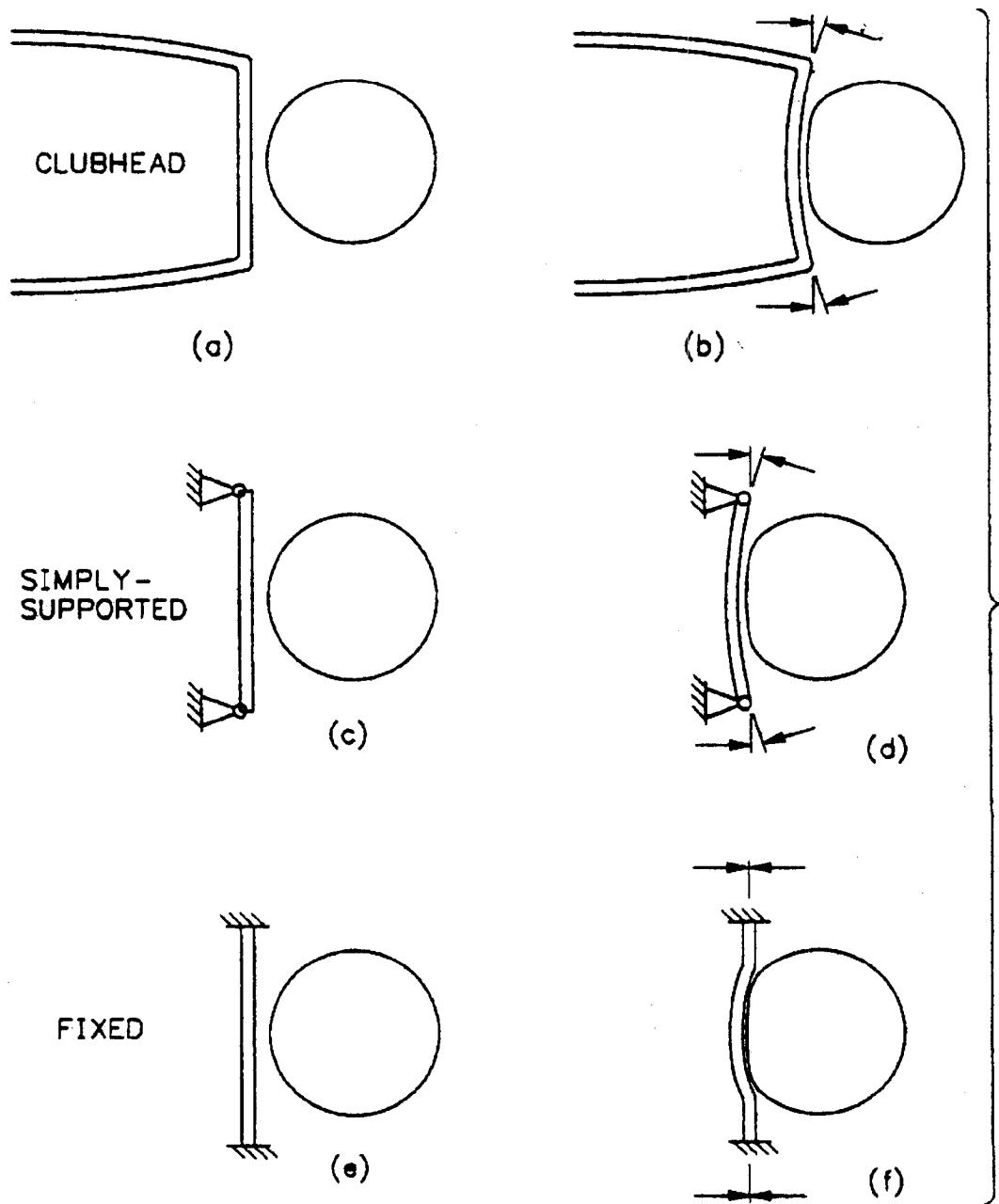


FIG. 5

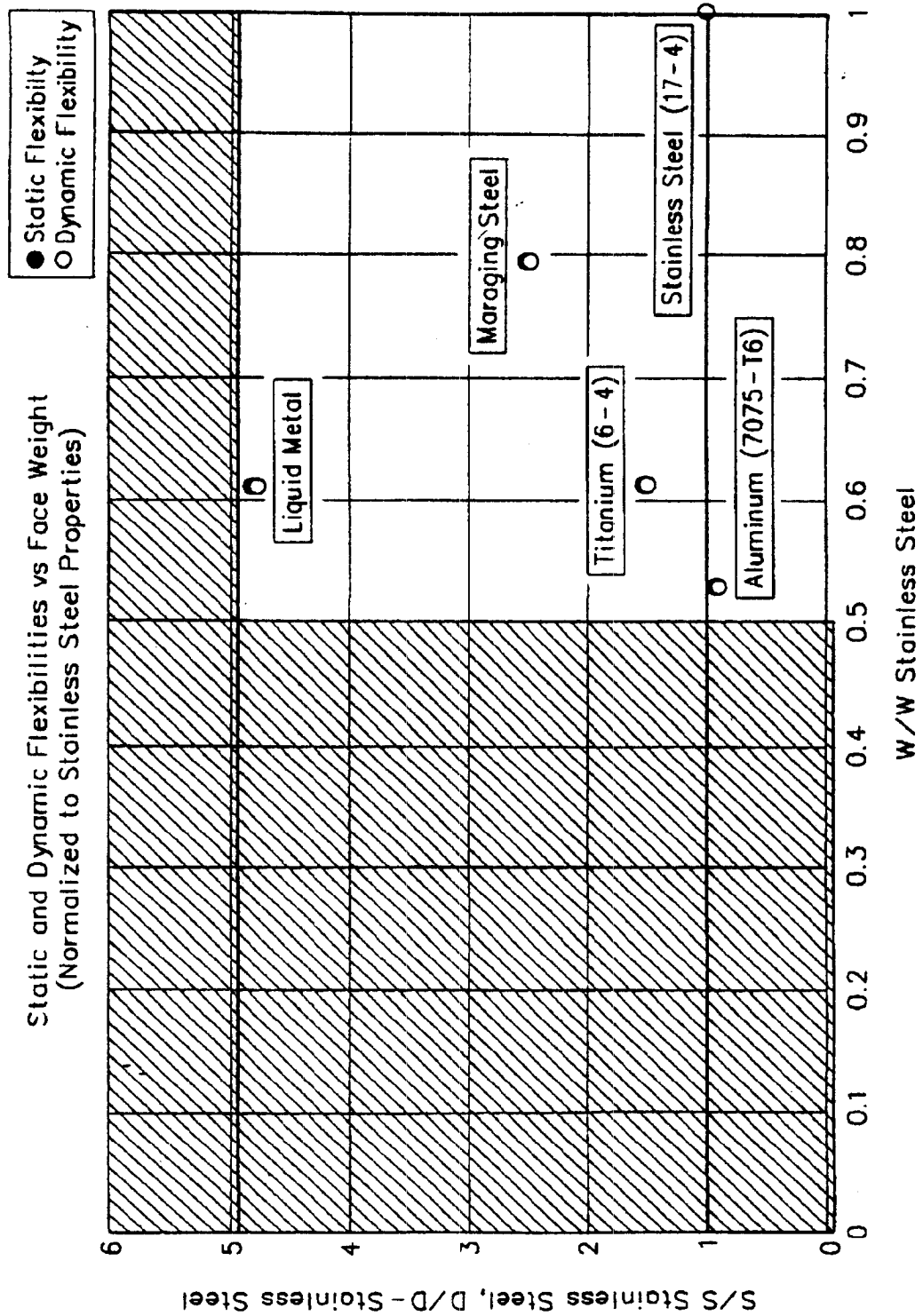


FIG. 6

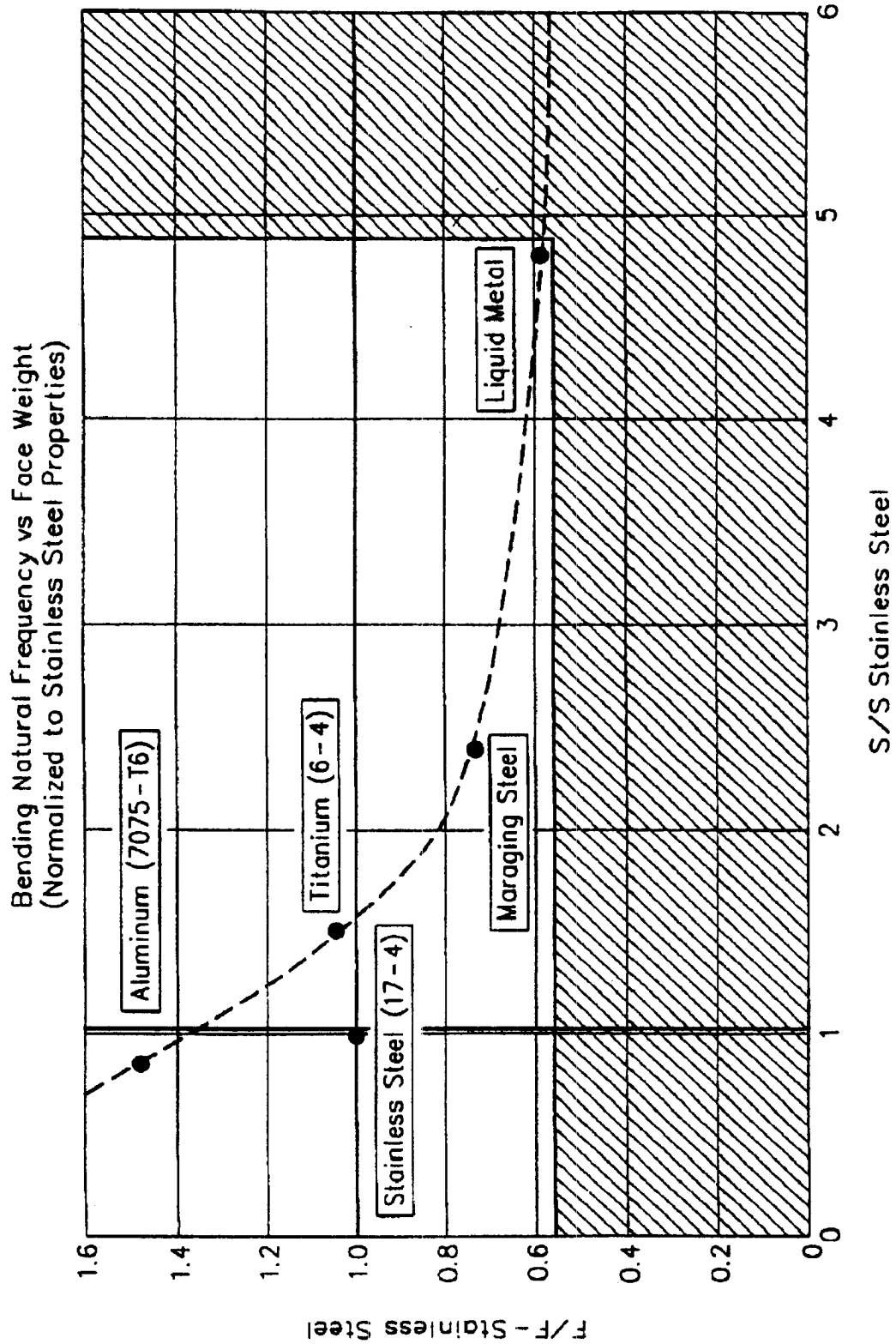


FIG. 7

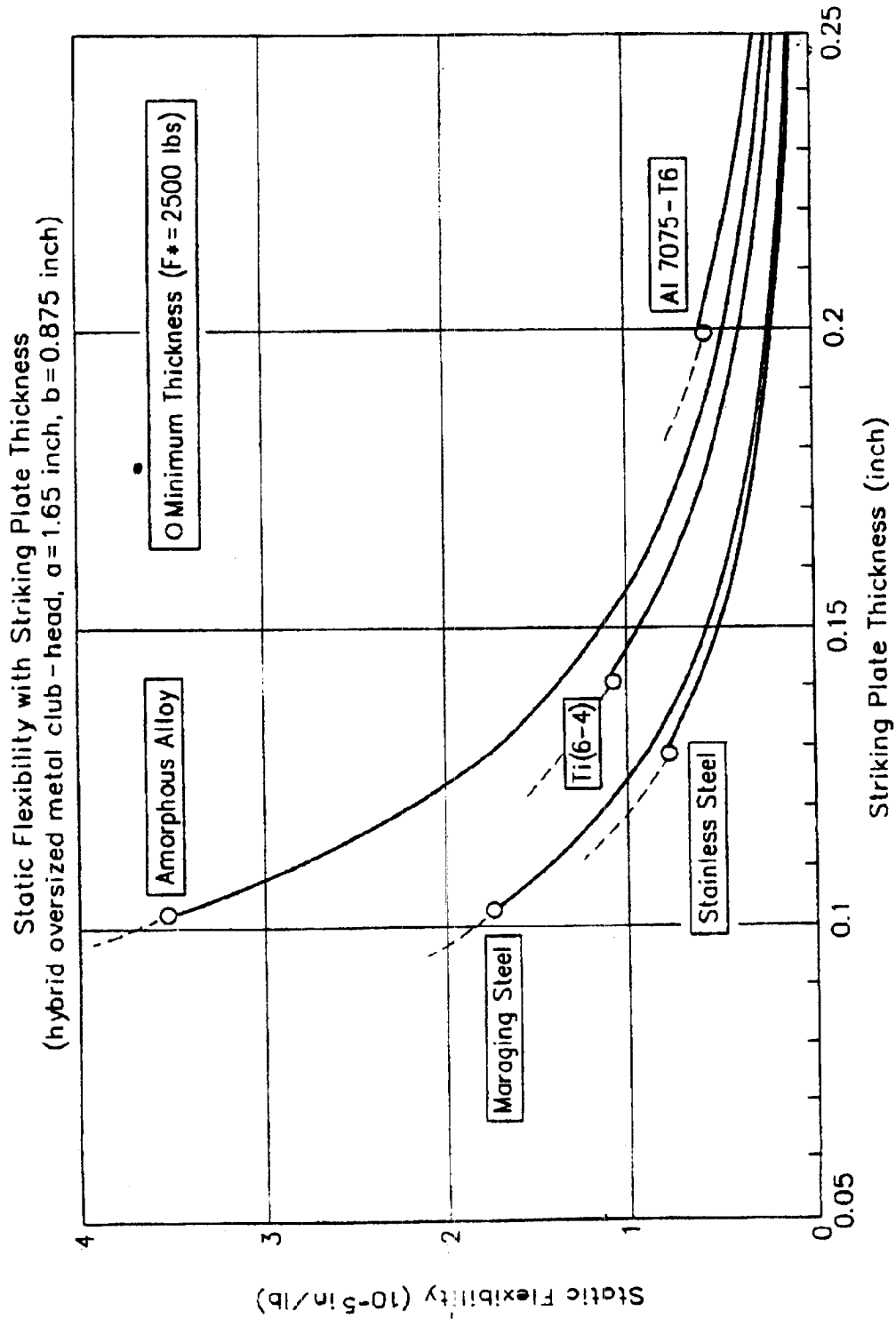
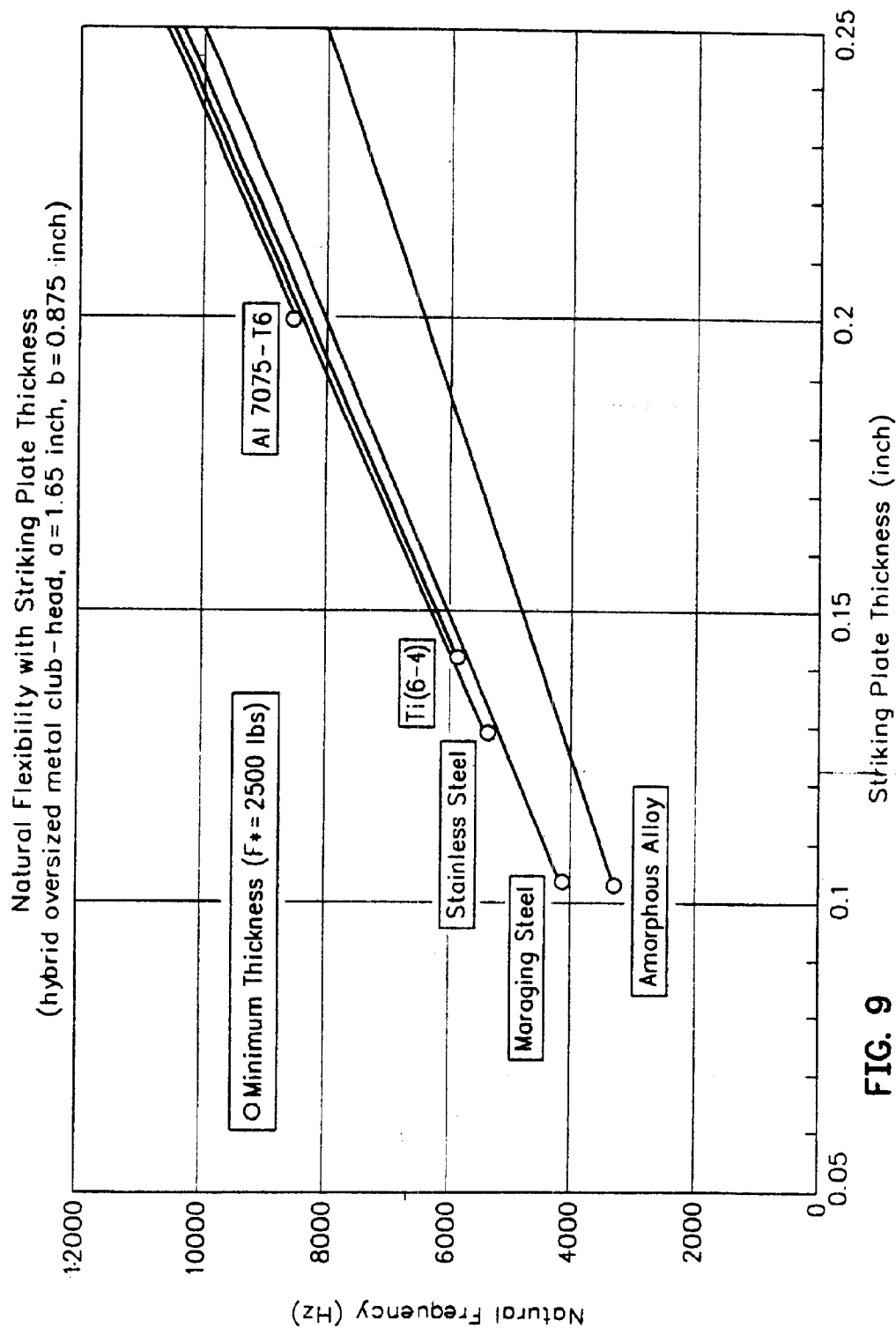


FIG. 8



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GOLF CLUB HEAD HAVING A STRIKING FACE WITH IMPROVED IMPACT EFFICIENCY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 09/525,216 filed on Mar. 14, 2000, now U.S. Pat. No. 6,348,015.

FEDERAL RESEARCH STATEMENT

[Not Applicable]

BACKGROUND OF INVENTION

1. Field of the Invention

The present invention relates to a golf club head. More specifically, the present invention relates to a face section of a golf club head to reduce energy losses when impacting a golf ball.

2. Description of the Related Art

Technical innovation in the material, construction and performance of golf clubs has resulted in a variety of new products. The advent of metals as a structural material has largely replaced natural wood for wood-type golf club heads, and is but one example of this technical innovation resulting in a major change in the golf industry. In conjunction with such major changes are smaller scale refinements to likewise achieve dramatic results in golf club performance. For example, the metals comprising the structural elements of a golf club head have distinct requirements according to location in the golf club head. A sole or bottom section of the golf club head should be capable of withstanding high frictional forces for contacting the ground. A crown or top section should be lightweight to maintain a low center of gravity. A front or face of the golf club head should exhibit high strength and durability to withstand repeated impact with a golf ball. While various metals and composites are known for use in the face, several problems arise from the use of existing materials. Existing golf club face materials such as stainless steel exhibit desired high strength and durability but incur large energy losses during impact with the golf ball as a result of large ball deformations. An improvement in impact energy conservation, in conjunction with proper golf ball launch parameters, is a design goal for golf club manufacturers. The problem still exists of identifying a combination of material properties exhibiting improvements in conservation of impact energy during impact with the golf ball.

SUMMARY OF INVENTION

When a golf club head strikes a golf ball, large impact forces are produced that load a face section, also called a striking plate, of the golf club head. Most of the energy is transferred from the golf club head to the golf ball; however, some energy is lost as a result of the impact. The present invention comprises a golf club striking plate material and geometry having a unique combination of material properties for improved energy efficiency during impact with the golf ball.

The golf ball is typically a core-shell arrangement composed of polymer cover materials, such as ionomers, surrounding a rubber-like core. The golf ball materials have stiffness properties defined as the storage and loss moduli for compression (E''_{ball} , E_{ball}) and storage and loss moduli for shear (G''_{ball} , G_{ball}) that are strain (or load), strain rate (or

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time rate of loading), input frequency, and temperature dependent. The compression loss factor (η_E) and shear loss factor (η_G) (damping or energy loss mechanisms), which are defined as the ratio of loss modulus to the storage modulus, are also strain, strain rate, input frequency, and temperature dependent. The golf ball loss factors, or damping level, is on the order of 10–100 times larger than the damping level of a metallic golf club striking plate. Thus, during impact most of the energy is lost as a result of the large deformations, typically 0.05 to 0.50 inches, and deformation rates of the golf ball as opposed to the small deformations of the metallic striking plate of the golf club head, typically 0.025 to 0.050 inches.

By allowing the golf club head to flex and cradle the golf ball during impact, the contact region as well as contact time between the golf ball and the striking plate of the golf club head are increased, thus reducing the magnitude of the internal golf ball stresses as well as the rate of the stress build-up. This results in smaller golf ball deformations and lowers deformation rates, both of which produce much lower energy losses in the golf ball during impact. The static flexibility is inversely proportional to the striking plate stiffness, while the dynamic flexibility is inversely proportional to square of the striking plate bending natural frequency. In other words, a decrease in plate stiffness will cause the static flexibility to increase, while doubling the plate bending natural frequency will reduce dynamic flexibility to a level $\frac{1}{4}$ of the original striking plate. Increasing the static or dynamic flexibility can be accomplished via several different configurations for the golf club head: altering geometry of the face section; altering attachment of the striking plate to the club-head body; reducing the thickness of the striking plate; or through the innovative use of new structural materials having reduced material stiffness and/or increased material density. Material strength of the striking plate of the golf club head in conjunction with impact load from contact with the golf ball determines the minimum required thickness for the face section. The greater the available material strength, the thinner the striking plate can be, and thus greater the flexibility. So the material properties that control static and dynamic flexibility are decreased compression stiffness, increased density, and increased strength.

The present invention specifies which face materials and static/dynamic flexibilities provide improved energy conservation during impact of the golf club head and the golf ball. Materials used in the face section of the golf club head constitute an additional important factor in determining performance characteristics of coefficient of restitution (COR), launch angle, spin rate and durability.

One object of the present invention is to improve impact efficiency between a golf club head and the golf ball.

Another object is to designate a range of material properties to increase the static flexibility, otherwise described as reduced bending stiffness, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

Another object is to designate a range of material properties to increase the dynamic flexibility, otherwise described as reduced bending natural frequency, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present

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invention to produce a compliant, or softer flexing performance during impact with the golf ball.

A further object of the present invention is a wood-type golf club head having a face section of a first material and a body section of a second material.

Another object of the present invention is a wood-type golf club head having a face section of a metal material. Another object of the present invention is a wood-type golf club head having a face section of a non-metal material.

Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of a golf club head of an embodiment of the present invention.

FIG. 2 is a front view of a golf club head showing a striking plate with a major cross-section dimensional width (W) and a minor cross-section dimensional height (H).

FIG. 3a shows a striking plate having an elliptical shape with a major and a minor cross-section dimensions (W) and (H), respectively of an embodiment of the present invention.

FIG. 4 shows an elliptical plate with a pressure loading over a central circular region.

FIG. 5a shows the face section of the club head, of an embodiment of the present invention, prior to impact with the golf ball.

FIG. 5b shows deformation of the striking plate of the golf club head, of an embodiment of the present invention, during impact with the golf ball.

FIG. 5c shows an elliptical striking plate having a simply-supported edge constraint prior to impact with the golf ball.

FIG. 5d shows deformation of the elliptical striking plate of FIG. 5c during impact with the golf ball.

FIG. 5e shows an elliptical striking plate having a fixed edge constraint prior to impact with a golf ball.

FIG. 5f shows the elliptical striking plate of FIG. 5e during impact with the golf ball.

FIG. 6 is a plot of the normalized static and dynamic flexibility versus the face weight for a minimum weight design.

FIG. 7 is a plot of the bending natural frequency versus the static flexibility for a minimum thickness design.

FIG. 8 is a plot of the static flexibility versus striking plate thickness for a large club h.

FIG. 9 is a plot of the natural frequency versus striking plate thickness for a large club head utilizing five different golf club striking plate materials.

DETAILED DESCRIPTION

As shown in FIG. 1 a wood-type golf club head 10 comprises a face section 12, a rear section 14, a top section 16, a bottom section 18, a toe section 20, a heel section 22 and a hosel inlet 24 to accept a golf shaft (not shown). The golf club head 10 is a unitary structure which may be composed of two or more elements joined together to form the golf club head 10. The face section 12, also called a striking plate, is an impact surface for contacting a golf ball (not shown). Structural material for the golf club head 10 can be selected from metals and non-metals, with a face material exhibiting a maximum limit for face stiffness and natural frequency being a preferred embodiment.

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The present invention is directed at a golf club head 10 having a striking plate 72 that makes use of materials to increase striking plate flexibility so that during impact less energy is lost, thereby increasing the energy transfer to the golf ball. This increased energy transfer to the golf ball will result in greater impact efficiency. The striking plate 12 is generally composed of a single piece of metal or nonmetallic material and may have a plurality of score-lines 13 thereon. The striking plate 12 may be cast with a body 26, or it may be attached through bonding or welding to the body 26. See FIGS. 1 and 2.

For explanation purposes, the striking plate 12 is treated as an elliptical shaped cross section having a uniform thickness, denoted as t in FIG. 4, that is subjected to a distributed load over a small circular region at the center of the striking plate 12. See FIGS. 3 and 4. Those skilled in the pertinent art will recognize that striking plates having other shapes, nonuniform thickness distribution, and force locations are within the scope and spirit of the present invention. The overall cross-section width is given by (W=2a), the overall cross-section height (H=2b), and the striking plate aspect ratio is defined as ($\alpha=b/a$). The impact load, resulting from impact of the golf ball with the golf club head 10, is treated as force of magnitude (F), acting with a pressure (q) over a circular region of radius (r_o) in the center of the elliptical plate so that

$$F = \int_0^{2\pi} \int_0^{r_o} q r dr d\theta.$$

Like other striking plates of the prior art, the striking plate 12 of the present invention is positioned between the top section 16 and bottom section 18. During impact with the golf ball, the striking plate 12 will deflect depending upon the connection to the top section 16 and the bottom section 18, see FIGS. 5a-f. The two extreme limiting cases for all possible boundary attachment conditions are defined as simply-supported where the elliptical edge of the striking plate is constrained from translating but the edge is free to rotate, see FIGS. 5c and 5d, and fixed or clamped where the elliptical edge is fixed from both translating and rotating, see FIGS. 5e and 5f. The boundary attachment for the striking plate 12 to the body 26 of the club head 10 will fall between the two limiting cases since the top section 16 and bottom section 18 will provide some stiffening to the striking plate 12, but in general are very close to the simply supported condition. The calculated maximum stress in the striking plate as a result of the applied loading is

$$\sigma = \frac{3(1+\nu)RF^*}{2\pi t^2}$$

where (F*) is the maximum load that includes the effects of design safety factors and the score-line 13 stress concentration factors, (t) is the plate thickness, (ν) is the material Poisson ratio, and (R) depends upon the plate geometry (a,b), load radius, material Poisson ratio, and edge support conditions. For golf club heads, the top section 16 and bottom section 18 provide some stiffening to the striking plate 12 edge, (R) will fall between the simply-supported edge and the fixed support, but for this invention it is very close to the simply-support edge condition;

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$$R_{\text{simply-support}} = \ln\left(\frac{b}{r_o}\right) + \frac{v}{(1+v)}(6.57 - 2.57\alpha) \quad (\text{IIIa,b})$$

$$R_{\text{fixed}} = \ln\left(\frac{2b}{r_o}\right) - .317\alpha - .376. \quad 5$$

The minimum required thickness of the striking face based upon the applied loading is determined by setting the maximum stress to the allowable material yield stress σ_{yield} and solving;

$$t = \sqrt{\frac{3(1+v)RF^*}{2\sigma_{\text{yield}}}}. \quad (\text{IV})$$

The minimum required striking plate thicknesses for two different materials (materials A and B) can be directly compared using Equation (IV), if one assumes that the impact forces, the plate geometry (W, H), and the edge boundary constraints are nearly the same. Writing the ratio of the minimum required thicknesses for two different materials is

$$\frac{t_A}{t_B} = \sqrt{\frac{\left(\frac{\sigma_{\text{yield-B}}}{\sigma_{\text{yield-A}}}\right)\left(\frac{1+v_A}{1+v_B}\right)}{1}}. \quad (\text{V}) \quad 25$$

where (t_A) and (t_B) are the minimum required thicknesses for plates composed of materials A and B, respectively, and ($\sigma_{\text{yield-A}}$, v_A) and ($\sigma_{\text{yield-B}}$, v_B) are the material properties of A and B, respectively. A weight ratio comparison of two minimum thickness striking plates is equal to

$$\frac{W_A}{W_B} = \frac{\rho_A t_A \pi ab}{\rho_B t_B \pi ab} = \frac{\rho_A}{\rho_B} \sqrt{\frac{\left(\frac{\sigma_{\text{yield-B}}}{\sigma_{\text{yield-A}}}\right)\left(\frac{1+v_A}{1+v_B}\right)}{1}}. \quad (\text{VI}) \quad 30$$

where (ρ_A) and (ρ_B) are the densities of material A and B, respectively, and these plates have identical geometry (W, H), boundary constraints, and are designed to withstand the same load (F^*).

Static Flexibility

The calculated striking plate static flexibility (S), which is the inverse of the plate stiffness, is defined as the calculated center displacement of the striking plate 12 divided by the plate force (F^*) and is equal to:

$$S = \frac{b^2}{Et^3} P. \quad (\text{VII}) \quad 40$$

where (b) is half the height of the striking plate 12, (E) is Young's modulus and (P) depends upon the geometry and the support conditions of the elliptical plate. For golf heads, (P) will fall between the simply-supported and fixed edge conditions, but for this invention it falls very close to the simply-supported edge condition;

$$P_{\text{simply-support}} = (.76 - .18\alpha) \quad [\text{t8}] \quad 60$$

$$P_{\text{fixed}} = (.326 - .104\alpha) \quad (\text{VIIIa,b})$$

Thus, increased striking plate flexibility can be accomplished by increasing the striking plate height (b), decreasing the Young's modulus (E), also described as material stiffness, or by reducing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable

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thickness from Equation (IV). Substituting Equation (IV) into (VII), results in the static flexibility having a minimum allowable plate thickness;

$$S = \left[\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+v} \right)^{3/2} \right] \left[P t^2 \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right], \quad (\text{IX})$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (P, R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are the same for two different designs (second bracketed term of Equation IX), then to maximize the static flexibility, one needs to select a material having the largest ratio of:

$$\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+v} \right)^{3/2}. \quad (\text{X})$$

The static flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (IX) as a ratio

$$\frac{S_A}{S_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{\sigma_{\text{yield-A}}}{\sigma_{\text{yield-B}}} \right)^{3/2} \left(\frac{1+v_B}{1+v_A} \right)^{3/2}, \quad (\text{XI})$$

where (S_A) and (S_B) are the static flexibilities of a plate having a minimum plate thickness for materials A and B, respectively and (E_A) and (E_B) are the material stiffnesses for materials A and B, respectively.

Bending Natural Frequency

The calculated bending natural frequency (ω), or referred to simply as natural frequency, having units of cycles/second (Hz), for the elliptical striking plate is given by;

$$\omega \text{ (Hz)} = \frac{\lambda t}{b^2} \sqrt{\frac{Eg}{\rho(1-v^2)}} \quad (\text{XII}) \quad 45$$

where (v) is the material Poisson ratio, (b) is half the height of the striking plate 12, (ρ) is the material weight density, (g) is the gravitational constant (32.2 ft/sec²), and (λ) depends upon the geometry and the support conditions of the elliptical plate, as well as the desired vibration mode. For golf club heads, (λ) will fall between the two limiting edge support values, simply-support and fixed, but for this invention it is very close to the simply-support condition;

$$\lambda_{\text{simply-support}} = 0.124 \sqrt{1 + 0.21\alpha + 2.37\alpha^2 - 3.03\alpha^3 + 2.7\alpha^4} \quad (\text{XIIa, b})$$

$$\lambda_{\text{fixed}} = 0.2877 \sqrt{1 + \frac{2}{3}\alpha^2 + \alpha^4}.$$

The bending natural frequency can be minimized by increasing the striking plate 12 height (2b) or aspect ratio (α), increasing the material density (ρ), decreasing the material stiffness (E), or decreasing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV) into (XII), results in the natural frequency having a minimum allowable plate thickness;

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$$\omega = \left[\sqrt{\frac{E}{\sigma_{yield}\rho(1-\nu)}} \right] \left[\frac{\lambda}{b^2} \sqrt{\frac{3gRF^*}{2\pi}} \right] \quad (XIV)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are the fixed (second bracketed term of Equation XIV), then to minimize the natural frequency, one needs to select a material having the smallest of:

$$\frac{E}{\sigma_{yield}\rho(1-\nu)} \quad (XV)$$

The natural frequency of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XIV) as a ratio

$$\frac{\omega_A}{\omega_B} = \sqrt{\frac{E_A}{E_B} \left(\frac{\sigma_{yield-B}}{\sigma_{yield-A}} \right) \left(\frac{\rho_B}{\rho_A} \right) \left(\frac{1-\nu_B}{1-\nu_A} \right)}, \quad (XVI)$$

where (ω_A) and (ω_B) are the natural frequencies of a striking plate having a minimum plate thickness for materials A and B.

A golf club head has a large number of natural frequencies, where some involve the vibratory motion that characterize the striking plate, others involve motion that characterize the top plate or bottom plate, and still others involve the combined motion of the striking plate and other parts of the club head. The natural frequencies that are of concern in the present invention involve the full or partial vibratory motion of the striking plate. Thus, to experimentally measure these frequencies, one needs to excite the striking plate as well as record its response. A noncontacting excitation and response system is preferred to insure that added mass or stiffness effects do not artificially alter the results. In our experimental studies, the striking plate was excited using either an impact hammer (PCB Inc. of Buffalo, N.Y., model 068, series 291; or Kistler Instrument Corp. of Amherst, N.Y., model 9722A500) or an acoustical funnel-cone speaker, where the speaker is driven with broad-band white random noise between 1000–10,000 Hz. The velocity time history (response) is measured using a laser velocimeter (Polytec PI GmbH of Waldbronn, Germany, model OFV-303 or PSV-300; or Ometron Inc. of London, England, model VPI-4000). The recorded excitation and response time histories are processed using a two-channel spectrum analyzer (Hewlett Packard of Palo Alto, Calif.) to determine the frequency content of the response signal divided by the excitation signal. The spectrum analyzer has input/output windowing features and anti-aliasing filters to eliminate processing errors. The test is repeated a minimum of 10 times and the data is averaged to minimize the effects of uncorrelated noise. Thus the coherence was found to be greater than 0.98 at all measured natural frequencies. The tests are repeated using numerous excitation and response locations on the striking plate to insure that the lowest striking plate dominated natural frequencies are recorded.

Dynamic Flexibility

The dynamic flexibility (D) for the striking plate is given by

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$$D = \frac{1}{m_e(2\pi\omega)^2}, \quad (XVII)$$

where, (ω) is the striking plate natural frequency, and (m_e) is the effective face mass that contributes to the dynamic response during impact:

$$m_e = \beta \frac{\rho}{g} \pi t a b = \beta \frac{\rho}{g} \pi \frac{b^2}{\alpha}. \quad (XVIII)$$

Here (β) is defined between (0) and (1), where (0) is associated with no face mass contributing to the dynamic response and (1) having all of the face mass contributing to the response. For golf clubs, ($0.15 < \beta < 0.35$). Writing the dynamic flexibility by substituting Equations (XIV) and (XVIII) into (XVII):

$$D = \frac{b^2}{E t^3} \left(\frac{\alpha(1-\nu^2)}{4\beta\pi^3\lambda^2} \right), \quad (XIX)$$

The striking plate dynamic flexibility can be increased by enlarging the plate depth (b) or aspect ratio (α), decreasing the material stiffness (E), or decreasing the plate thickness (t). Clearly the greatest increase in (D) can be found by changing the thickness (t), followed by changing the face height (2b). But, the plate thickness can only be reduced up to the allowable value of Equation (IV). Thus, the maximum dynamic flexibility (D) for a given plate geometry and applied load is calculated by substituting the minimum allowable thickness Equation (IV) into (XIX);

$$D = \left[\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \right] \left[\left(\frac{\alpha b^2}{4\beta\pi^3\lambda^2} \right) \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right] \quad (XX)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (λ , R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are constant (second bracketed term of Equation XX), then to maximize the dynamic flexibility

(D), one needs to select a material having the largest ratio of:

$$\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \quad (XXI)$$

The dynamic flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XX) as a ratio

$$\frac{D_A}{D_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{1-\nu_A^2}{1-\nu_B^2} \right) \left(\frac{\sigma_{yield-A}}{\sigma_{yield-B}} \right)^{3/2} \left(\frac{1+\nu_A}{1+\nu_B} \right)^{3/2}, \quad (XXII)$$

where (D_A) and (D_B) are the maximum dynamic flexibilities of a plate having a minimum plate thickness for materials A and B, respectively.

For wood-type golf clubs the following geometry and force properties are typical (a=1.4–1.65 inch, b=0.7–1.0 inch, t=0.14–0.25 inch, $F^*=2000$ –15,000 lbs). In Table 1, current metal golf club head material properties are given

along with five different golf club head property ratios. These five different ratios include: minimum required striking plate thickness (Eq. V), resulting striking plate weight (Eq. VI), static flexibility (Eq. XI), bending natural frequency (Eq. XVI), and dynamic flexibility (Eq. XXII), where the baseline (B) material is taken as (17-4) Stainless Steel. These ratios provide a comparison of striking plates that have identical elliptical geometry, edge attachment, and load capacity, but are composed of different materials and thus will have different minimum striking plate thicknesses. A normalized comparison of the static flexibility and dynamic flexibility to face weight is presented in FIG. 6, where all results are normalized to an equivalent (17-4) Stainless Steel striking plate. In FIG. 6, it is clear that the amorphous alloy striking plate and maraging striking plate offer (4.8) and (2.5) times more flexibility and lower face weight than stainless steel as a result of their high strength, while the titanium alloy striking plate offers 50% more flexibility and lower face weight as a result of significantly lower modulus, but that the aluminum alloy striking plate

a preferred embodiment the striking plate of aluminum alloy has a maximum thickness of less than 0.200 inches, and more preferably between 0.200 and 0.070 inches. The striking plates composed of an amorphous alloy, Maraging 280 steel, and the 6-4 Titanium all have static and dynamic flexibilities much greater than the 17-4 Stainless Steel striking plate (480%, 240% and 150%), while the aluminum alloy striking plate has a 12% lower flexibility as a result of its large thickness. Finally, the striking plates composed of amorphous alloy and maraging steel have bending natural frequencies which are 41% and 27% lower, respectively, than the 17-4 Stainless Steel striking plate, whereas the titanium alloy striking plate is nearly the same as the stainless steel, while the aluminum alloy striking plate is 50% greater as a result of an increased thickness and low density. It should be further pointed out, that most golf club designers use the striking plate weight savings to further increase the size of the striking plate (i.e. oversize titanium drivers) and thus further increase its static and dynamic flexibility.

TABLE 1

Typical Material Properties used in Golf Club Faces and Comparison Ratios

Material (i)	E 10 ⁶ lb/in ²	ν	σ_{yield} 10 ³ lb/in ²	ρ lb/in ³	t_i/t_{steel}	W_i/W_{steel}	S_i/S_{steel}	$\omega_i/\omega_{\text{steel}}$	D_i/D_{steel}
Stainless Steel(17-4)	29.0	.27	150	.276	1.00	1.00	1.00	1.00	1.00
Aluminum (7075-T6)	10.4	.33	73	.101	1.47	0.34	0.88	1.48	0.85
Titanium (Ti 6-4)	16.0	.31	138	.160	1.06	0.61	1.53	1.05	1.49
Maraging 280 Steel	26.5	.31	262	.285	0.77	0.79	2.41	0.73	2.35
Amorphous Alloy	13.3	.30	260	.220	0.77	0.61	4.80	0.59	4.72

results in lower flexibility as a result of its lower strength. These increases in flexibility lead to reduced impact energy losses, which in turn lead to greater golf ball flight velocities. In FIG. 7, a comparison of normalized face natural frequency versus static flexibility is presented, where a correlation exists between measured natural frequency and static flexibility, and thus natural frequency can be used as a simple nondestructive measurement technique for assessing the magnitude of the static and dynamic flexibility. It is observed that the amorphous alloy and maraging steel striking plates have a lower natural frequency and greater flexibility than other materials in FIG. 7 because of their high strength and density. The titanium alloy striking plate and aluminum alloy striking plate have natural frequencies higher than all the other materials in FIG. 7 because of their low density. A detailed inspection of Table 1 reveals that striking plates composed of Maraging 280 steel or the amorphous alloy are 23% thinner than the 17-4 Stainless Steel striking plate, which is a direct result of higher strength of these materials. In a preferred embodiment the striking plate of stainless steel has a maximum thickness of less than 0.130 inches, and more preferably between 0.130 and 0.070 inches, while both the maraging steel and amorphous alloy have a striking plate thickness of less than 0.100 inches, and more preferably between 0.100 and 0.070 inches. The Aluminum 7075-T6 striking plate is thickest because of its low strength, but it is the lightest as a result of its low density. In

As a second example, consider a very large oversized driver head similar to a Callaway Golf® Biggest Big Bertha driver that is fabricated with different material striking plates. The geometry values are defined as ($a=1.65$ inch, $b=0.875$ inch, $\alpha=0.530$). In order to produce striking plate flexibility levels greater than found in any current club-head: (1) the striking plate has no scorelines, thus ($F^*=2500$ lbs) with a radius ($r_o=0.50$ inch), and (2) the edge attachment condition is nearly simply-supported so that ($P=0.664$, $\zeta=0.1538$). Constructing the striking plate out of Titanium (Ti 6-4), leads to ($R=1.792$) and a minimum required face thickness of ($t=0.143$ inch). Including score-line stress concentration factors will simply increase (F^*), thus increasing the required face thickness (t) and bending natural frequency, and decreasing the flexibility. The calculated weight is ($W=0.103$ lb), the static flexibility is ($S=1.10 \times 10^{-5}$ in/lb), the natural frequency ($\omega=5920$ Hz), and the dynamic flexibility ($D=1.08 \times 10^{-5}$ in/lb), where it was assumed ($\beta=0.25$). The calculated head natural frequency of 5920 Hz is within 2% of the experimentally measured value of 6040 Hz on an actual experimental hybrid golf club head. The maximum displacement of the striking plate is found by multiplying the static flexibility and the effective force (F^*), thus ($\beta=0.0275$ inch). Hybrid golf club heads having different material striking face plates are presented in Table 2, where the striking plates have minimum allowable face thicknesses. In FIGS. 8 and 9, the variation of the static

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flexibility and natural frequency with striking plate thickness is presented for the five different metals, where the symbol (o) is used to represent the minimum allowable thickness for a assumed applied load (F*=2500 lbs). Clearly, if the applied load were increased then the minimum allowable thicknesses would increase, where the symbols would just move

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striking plate 12, the natural frequency is below 6000 Hz, and in a more preferred embodiment the natural frequency is between 6000 Hz and 2800 Hz. For the amorphous alloy striking plate 12, the natural frequency is below 5500 Hz, and in a more preferred embodiment the natural frequency is between 5500 Hz and 2800 Hz.

TABLE 2

Calculated Striking Plate Properties for a Hybrid Oversized Driver Golf Club Head without scorelines (a = 1.65, b = .875, α = .530, F* = 2500 lb, r_o = 0.5, P = 0.664, λ = .154, β = 0.25).
[t22]

Material (i)	E 10 ⁶ lb/in ²	ν	σ _{yield} 10 ³ lb/in ²	ρ lb/in ³	R	T Inch	W lb	S 10 ⁻⁵ in/lb	Δ inch	ω (Hz)	D 10 ⁻⁵ in/lb
Stainless Steel(17-4)	29.0	.27	150	.276	1.67	.130	.162	.803	.020	5458	.809
Aluminum (7075-T6)	10.4	.33	73	.101	1.85	.200	.092	.605	.015	8520	.586
Titanium (Ti 6-4)	16.0	.31	138	.160	1.79	.142	.103	1.10	.027	5920	1.08
Maraging 280 Steel	26.5	.31	262	.285	1.79	.103	.134	1.74	.043	4143	1.71
Amorphous Alloy	13.3	.30	260	.220	1.76	.102	.102	3.55	.089	3304	3.51

to the right along the appropriate curve. Thus lowering the flexibility and increasing the natural frequency. Moreover, if a higher strength version of an alloy were used, then the symbol would follow the curve to the left and thus increase the flexibility and lower natural frequency. It is observed that the greatest flexibility occurs for maraging steel and the amorphous alloy, which has the thinnest striking plates and lowest natural frequencies. It is known through experimental testing, that currently available driver golf club heads have striking-face natural frequencies greater than 4500 Hz. Moreover, the only commercially available golf club head with an amorphous alloy striking plate (commercial name: Liquid Metal®) has a fundamental striking plate natural frequency of 5850 Hz. Thus, the striking plates on these club heads are not optimized for maximum flexibility. They do not have a minimum thickness striking plate, a large aspect ratio, or an edge support that simulates the simply supported constraint. From Equation XVII, the dynamic flexibility is inversely proportional to the square of the natural frequency, thus these heads have a flexibility that is much lower and a face thickness that is much greater than the optimized minimum values presented in the previous example (i.e. their values on FIGS. 8 and 9 would be to the far right of the minimum allowable thickness). In a preferred embodiment of the present invention, the material of striking plate 12 has a natural frequency of less than 4500 Hz, in a more preferred embodiment the striking plate 12 natural frequency is between 4500 Hz and 2800 Hz. For the aluminum alloy striking plate 12, the natural frequency is below 8500 Hz, and in a more preferred embodiment the natural frequency is between 8500 Hz and 2800 Hz. For the titanium alloy striking plate 12, the natural frequency is below 5900 Hz, and in a more preferred embodiment the natural frequency is between 5900 Hz and 2800 Hz. For the stainless steel striking plate 12, the natural frequency is below 5400 Hz, and in a more preferred embodiment the natural frequency is between 5400 Hz and 2800 Hz. For the maraging steel

Although the above description is for wood-type golf club heads having an elliptical face section, the present invention is not limited to such an embodiment. Also included within the bounds of the present invention are iron type golf club heads and golf club heads with α values approaching 1.0. The golf club head 10 is a fairway wood or a driver. The golf club head 10 has a body 26, excluding the striking plate 12, that is preferably composed of a metal material such as titanium, titanium alloy, stainless steel, or the like, and is most preferably composed of a forged titanium material. However, the body 26, or a portion of the body 26, may be composed of a graphite composite material or the like. The body 26 preferably has a large volume, most preferably greater than 300 cubic centimeters, more preferably 300 cubic centimeters to 450 cubic centimeters, even more preferably 350 cubic centimeters to 400 cubic centimeters, and is most preferably 385 cubic centimeters for a body composed of titanium, or titanium alloy. However, a body 26 composed of stainless steel may have a volume range of 200 cubic centimeters to 325 cubic centimeters, and a body 26 composed of a composite material (such as plies of continuous carbon fiber pre-preg material) may have a volume of 325 cubic centimeters to 600 cubic centimeters. The body 26 preferably weighs no more than 215 grams, and most preferably weighs between 180 and 205 grams. The body 26 has a hollow interior. From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

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What is claimed is:

1. A golf club head comprising:
a body;
an elliptical striking plate connected to the body, the striking plate composed of a first material, and having a natural frequency less than 4000 Hz and greater than 2800 Hz.
2. A golf club head comprising:
a body composed of stainless steel and having a volume ranging from 200 cubic centimeters to 325 cubic centimeters; and
a striking plate connected to the body, the striking plate composed of a first material, and having a natural frequency less than 3300 Hz and greater than 2800 Hz.
3. A golf club head comprising:
a body composed of a first metal material, the body having a top region, a bottom region, a rear region and an open front, the first material selected from the group consisting of titanium, titanium alloy, steel alloy and composite materials; and
a striking plate composed of a second material and having a natural frequency less than 8500 Hz and greater than 2800 Hz, and the striking plate disposed in the open front of the body.
4. The golf club head of claim 3, wherein the second material is aluminum alloy.
5. The golf club head of claim 4, wherein the second material is titanium alloy having a natural frequency less than 5900 Hz and greater than 2800 Hz.

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6. The golf club head of claim 4, wherein the second material is stainless steel having a natural frequency less than 5400 Hz and greater than 2800 Hz.
7. The golf club head of claim 3, wherein the striking plate has a maximum thickness of less than 0.200 inches.
8. The golf club head of claim 3, wherein the maximum thickness of the striking plate is less than 0.200 inches and greater than 0.070 inches.
9. The golf club head of claim 3, wherein the striking plate has a maximum thickness of less than 0.140 inches.
10. The golf club head of claim 3, wherein the maximum thickness of the striking plate is less than 0.140 inches and greater than 0.070 inches.
11. The golf club head of claim 3, wherein the striking plate has a maximum thickness of less than 0.130 inches.
12. A golf club head comprising:
a body composed of a titanium alloy material, the body having a top region, a bottom region, a rear region and an open front, the body having a volume ranging from 300 cubic centimeters to 450 cubic centimeters; and
a striking plate composed of a metal material and having a natural frequency less than 8500 Hz and greater than 2800 Hz, a maximum thickness of the striking plate is less than 0.200 inches and greater than 0.070 inches, and the striking plate disposed in the open front of the body.

* * * * *

Exhibit C

(12) **United States Patent**
Kosmatka

(10) **Patent No.:** **US 6,669,579 B2**
(45) **Date of Patent:** **Dec. 30, 2003**

(54) **GOLF CLUB HEAD HAVING A STRIKING
FACE WITH IMPROVED IMPACT
EFFICIENCY**

(75) Inventor: **John B. Kosmatka**, Encinitas, CA (US)

(73) Assignee: **Callaway Golf Company**, Carlsbad,
CA (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 44 days.

(21) Appl. No.: **10/065,690**

(22) Filed: **Nov. 8, 2002**

(65) **Prior Publication Data**

US 2003/0190974 A1 Oct. 9, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/683,799, filed on Feb.
15, 2002, now Pat. No. 6,478,692, which is a continuation-
in-part of application No. 09/525,216, filed on Mar. 14,
2000, now Pat. No. 6,348,015.

(51) **Int. Cl.**⁷ **A63B 53/04**

(52) **U.S. Cl.** **473/342; 473/329; 473/345;**
473/349; 473/350

(58) **Field of Search** 473/324, 332,
473/349, 350, 329, 342, 345, 346, 290,
291

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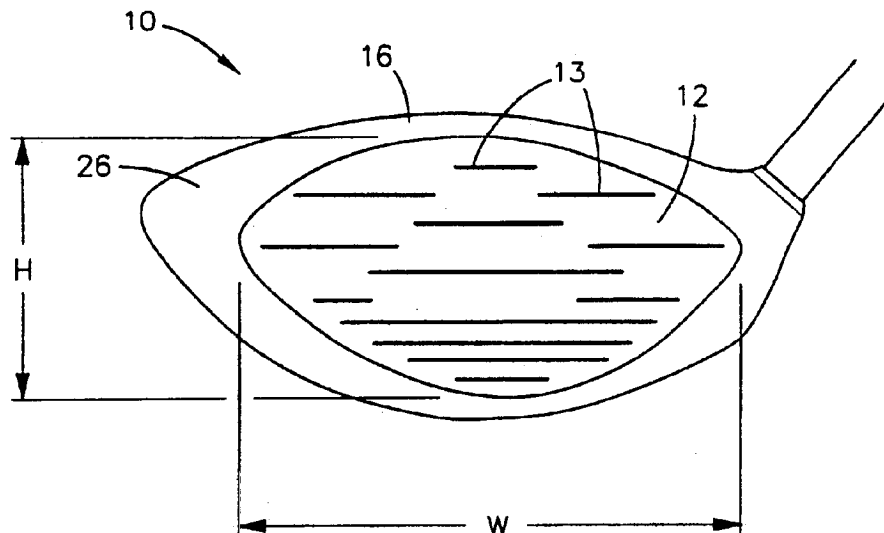
Primary Examiner—Raleigh W. Chiu

(74) *Attorney, Agent, or Firm*—Michael A. Catania; Elaine
H. Lo

(57) **ABSTRACT**

A compliant golf club head permits a more efficient impact
between a golf ball and the golf club head. Material and
geometry constraints of a striking plate of the golf club head
can reduce energy losses caused by large strain and strain
rate values of the golf ball, these constraints on the striking
plate yield a measure of the impact efficiency of the golf club
head. Designating a required natural frequency range of the
striking plate provides improved impact efficiency between
the golf ball the golf club head.

7 Claims, 7 Drawing Sheets



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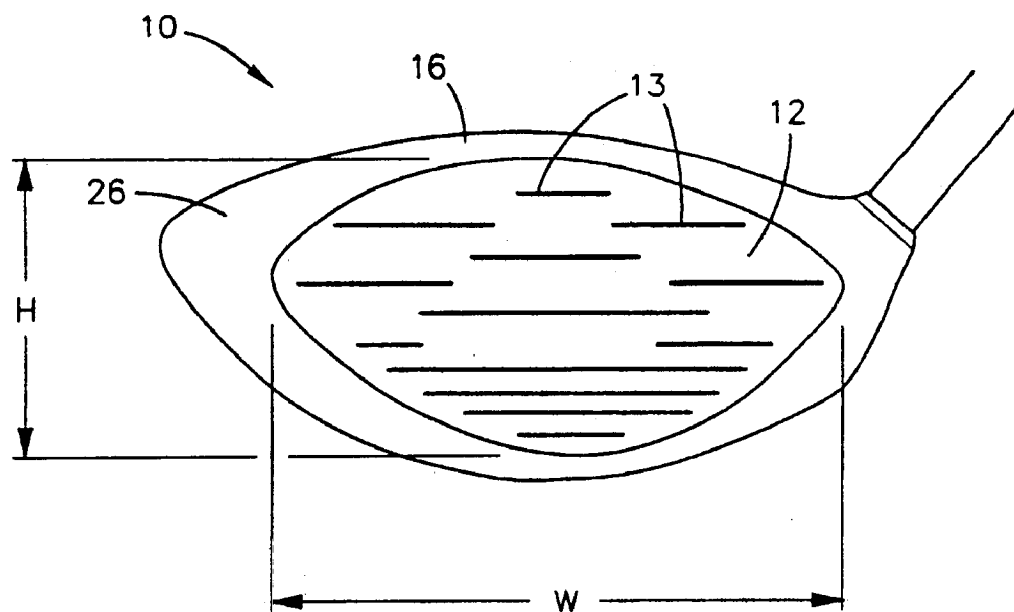
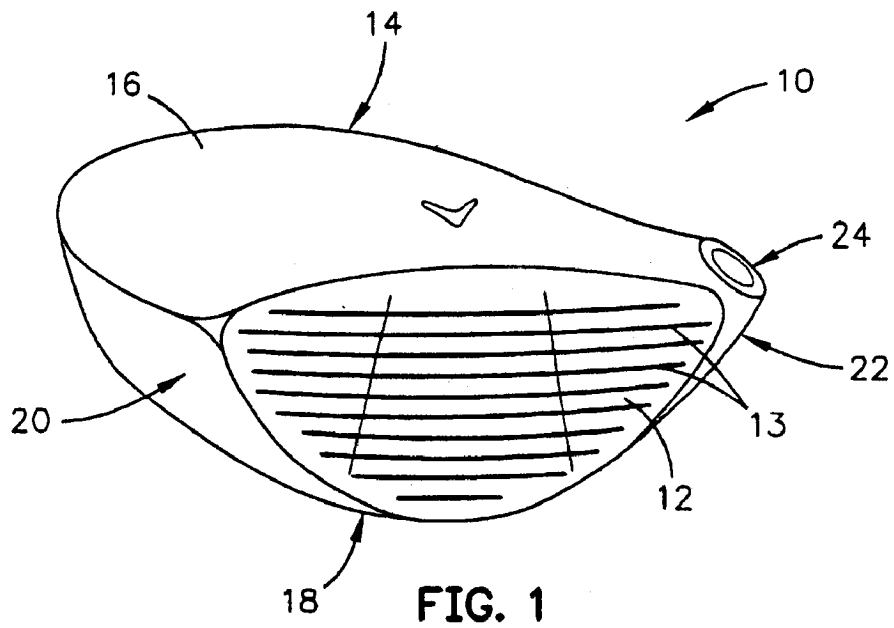


FIG. 2

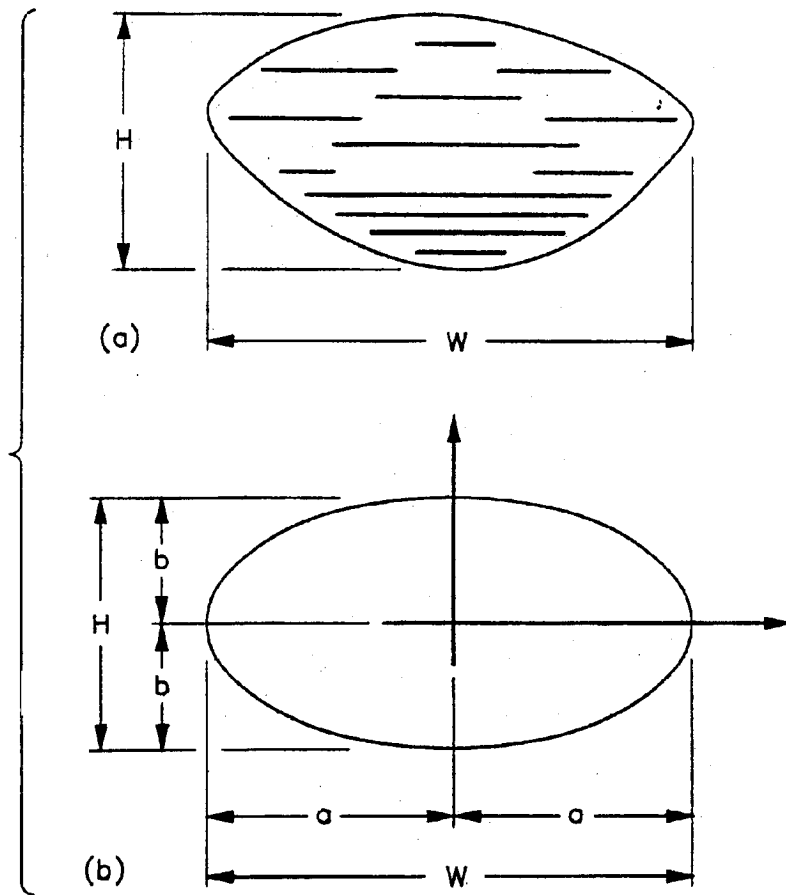


FIG. 3

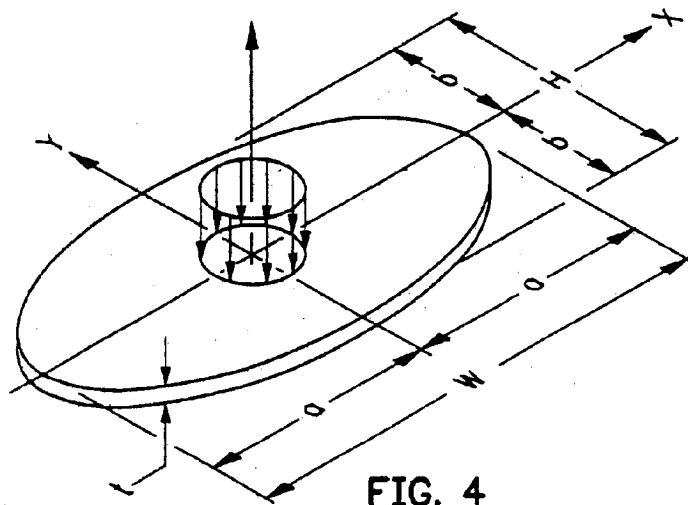


FIG. 4

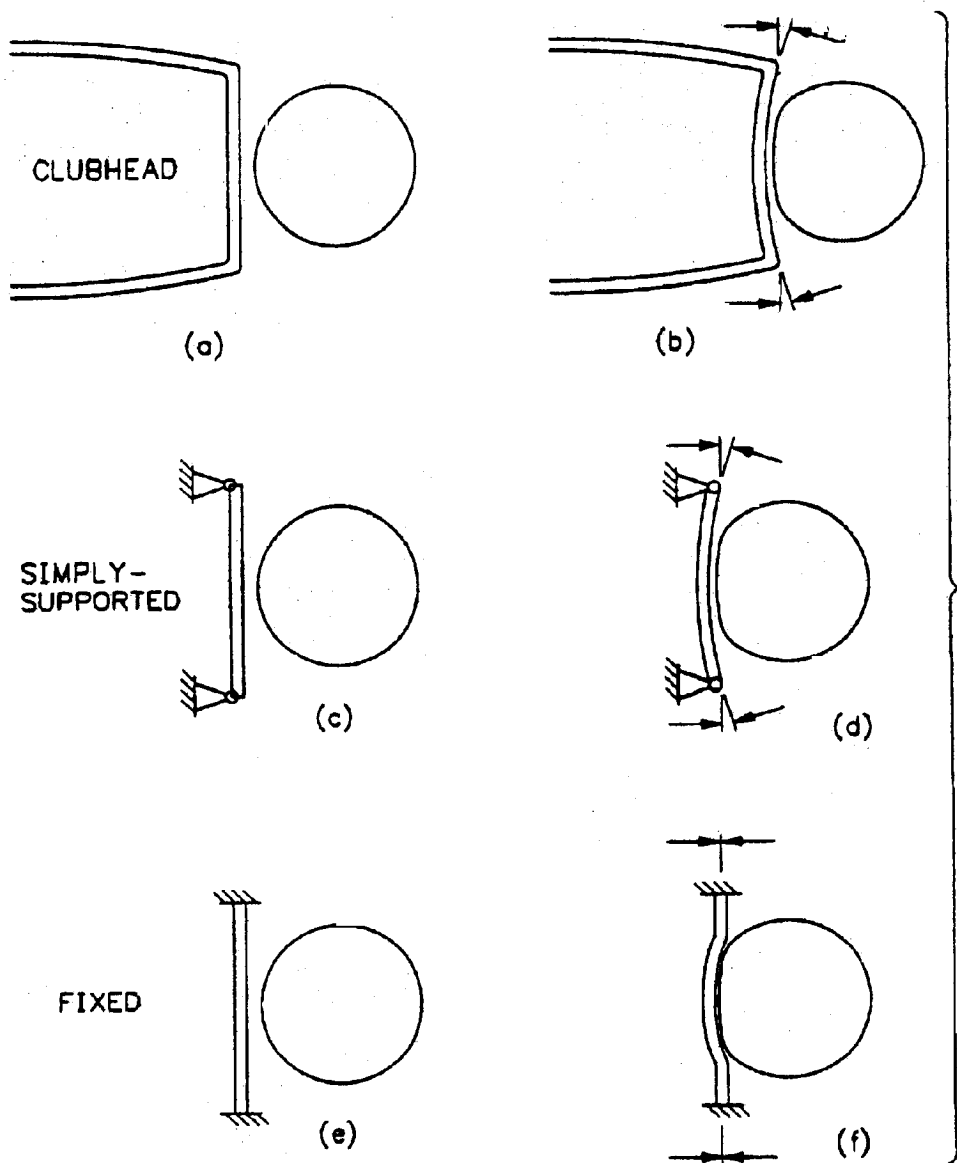


FIG. 5

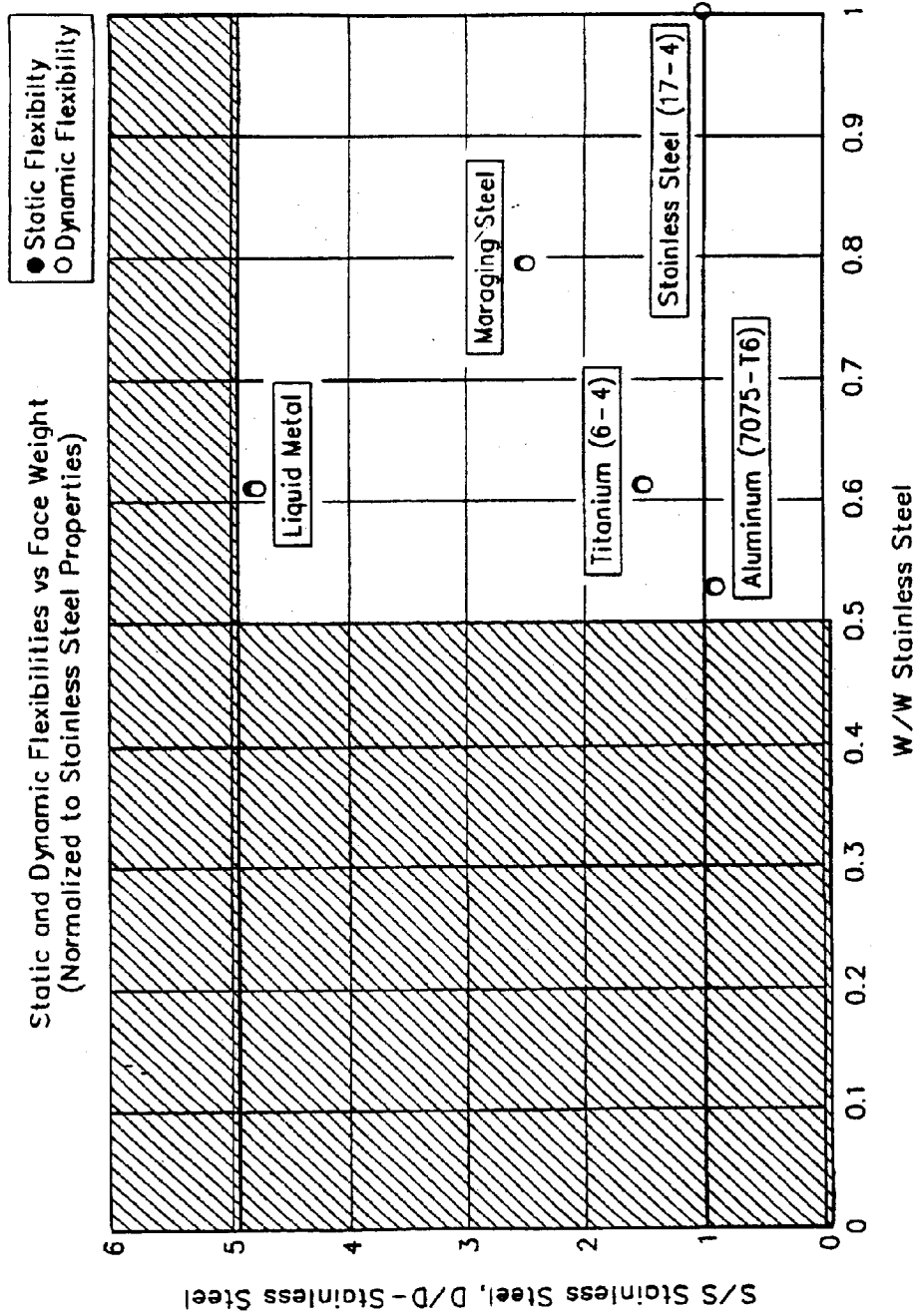


FIG. 6

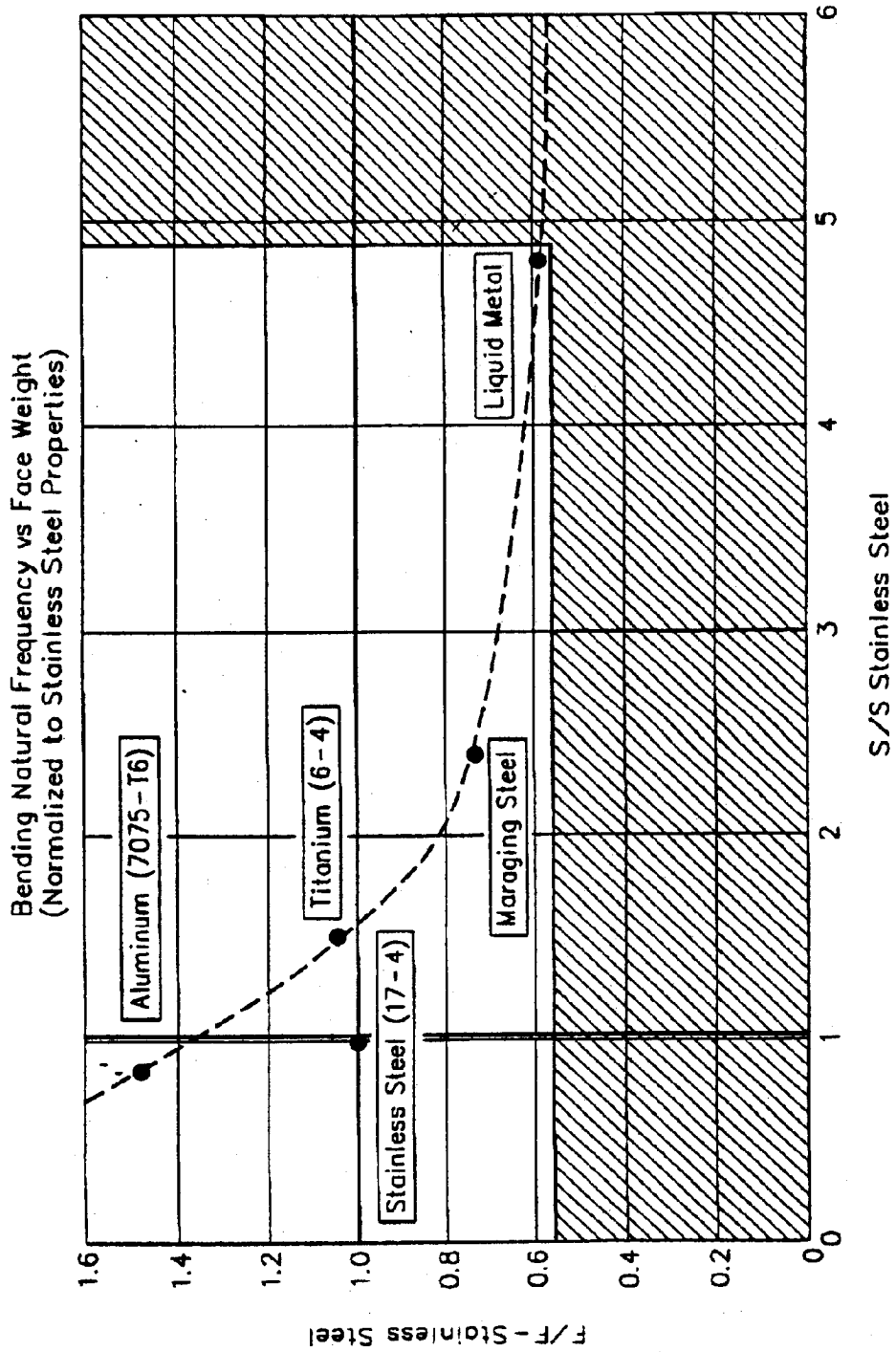


FIG. 7

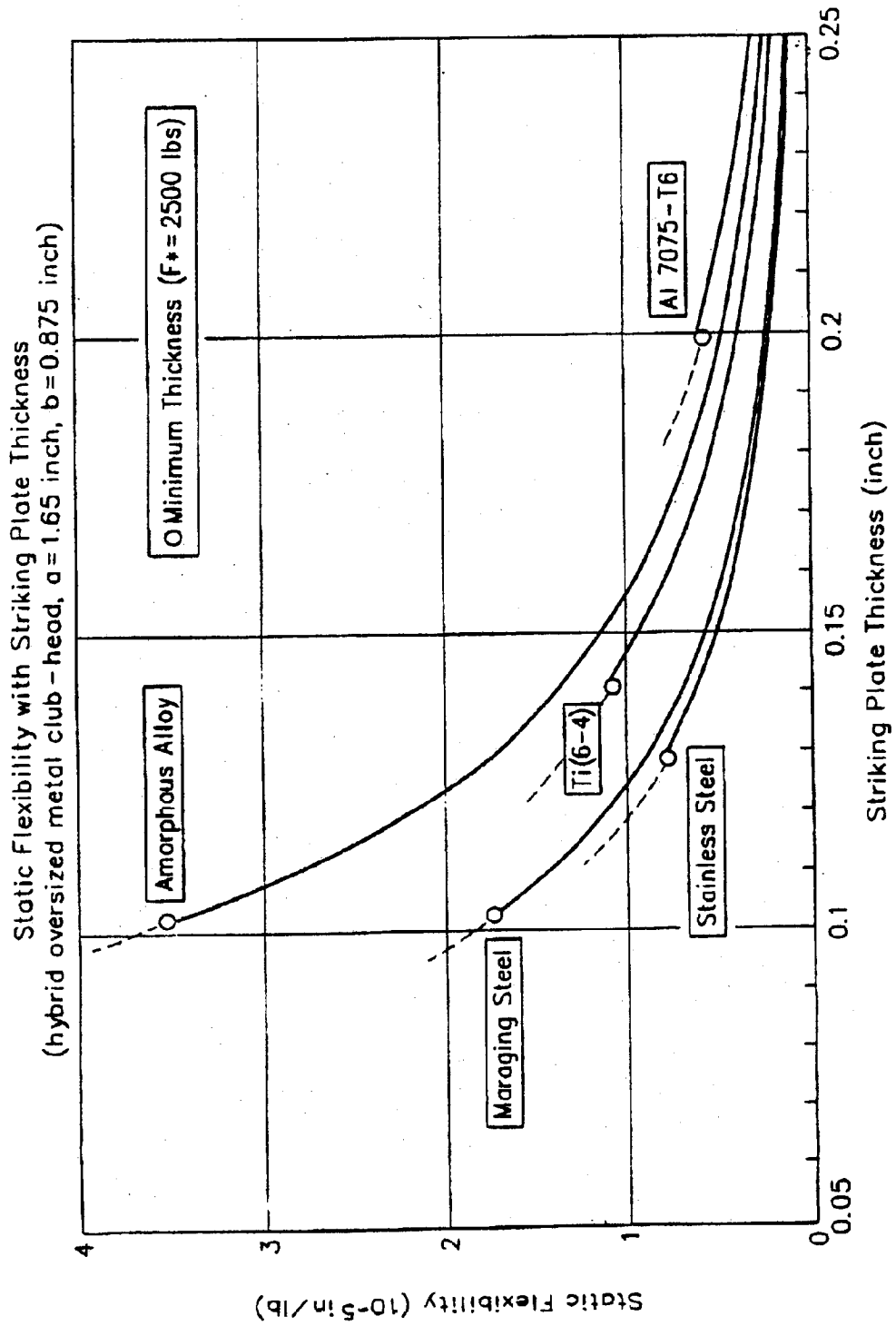
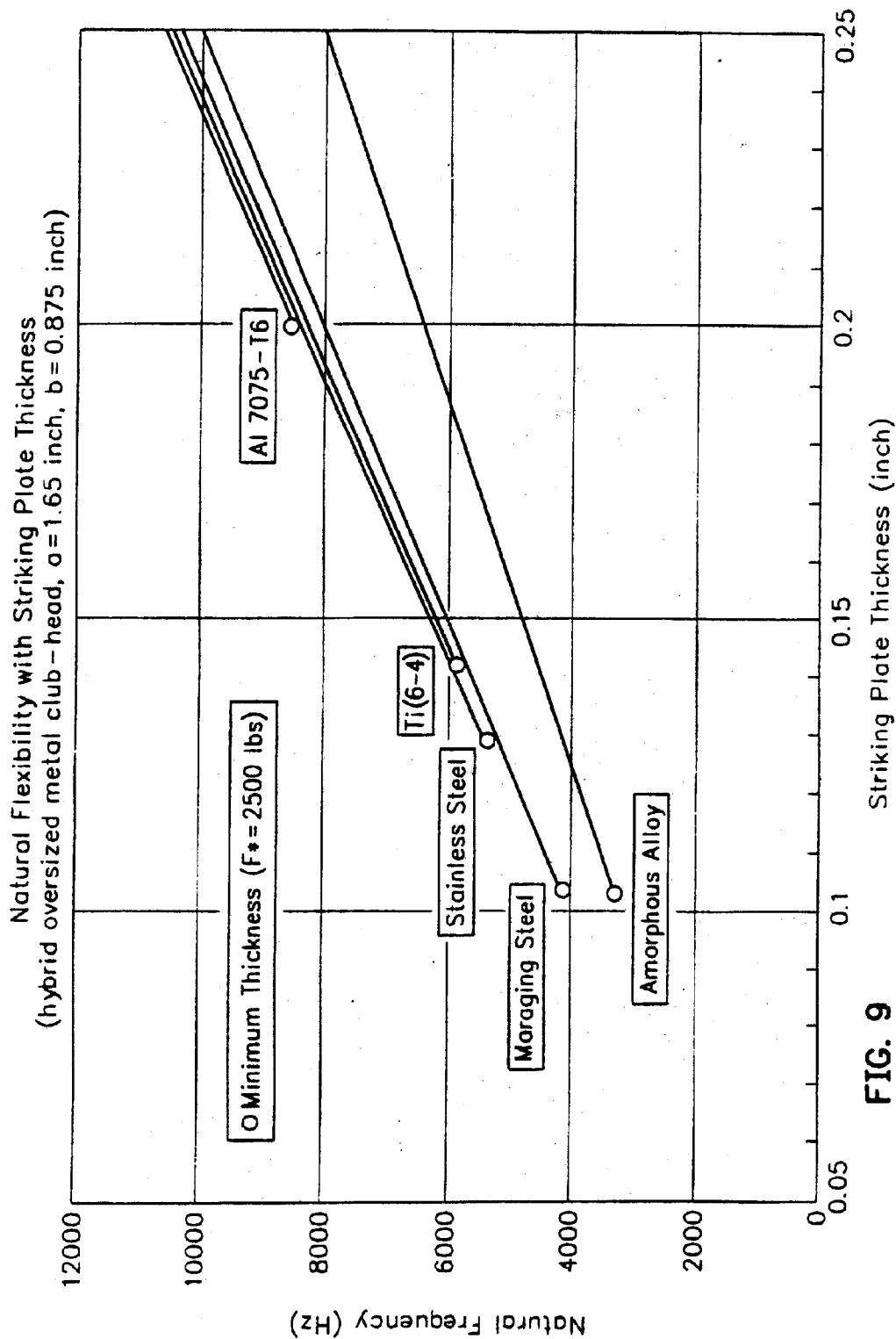


FIG. 8



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GOLF CLUB HEAD HAVING A STRIKING FACE WITH IMPROVED IMPACT EFFICIENCY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 09/683,799, filed on Feb. 15, 2002 now U.S. Pat. No. 6,478,692, which is a continuation-in-part application of U.S. patent application Ser. No. 09/525,216 filed on Mar. 14, 2000, now U.S. Pat. No. 6,348,015 issued Feb. 19, 2002.

FEDERAL RESEARCH STATEMENT

[Not Applicable]

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a golf club head. More specifically, the present invention relates to a face section of a golf club head to reduce energy losses when impacting a golf ball.

2. Description of the Related Art

Technical innovation in the material, construction and performance of golf clubs has resulted in a variety of new products. The advent of metals as a structural material has largely replaced natural wood for wood-type golf club heads, and is but one example of this technical innovation resulting in a major change in the golf industry. In conjunction with such major changes are smaller scale refinements to likewise achieve dramatic results in golf club performance. For example, the metals comprising the structural elements of a golf club head have distinct requirements according to location in the golf club head. A sole or bottom section of the golf club head should be capable of withstanding high frictional forces for contacting the ground. A crown or top section should be lightweight to maintain a low center of gravity. A front or face of the golf club head should exhibit high strength and durability to withstand repeated impact with a golf ball. While various metals and composites are known for use in the face, several problems arise from the use of existing materials.

Existing golf club face materials such as stainless steel exhibit desired high strength and durability but incur large energy losses during impact with the golf ball as a result of large ball deformations. An improvement in impact energy conservation, in conjunction with proper golf ball launch parameters, is a design goal for golf club manufacturers. The problem still exists of identifying a combination of material properties exhibiting improvements in conservation of impact energy during impact with the golf ball.

SUMMARY OF INVENTION

When a golf club head strikes a golf ball, large impact forces are produced that load a face section, also called a striking plate, of the golf club head. Most of the energy is transferred from the golf club head to the golf ball; however, some energy is lost as a result of the impact. The present invention comprises a golf club striking plate material and geometry having a unique combination of material properties for improved energy efficiency during impact with the golf ball.

The golf ball is typically a core-shell arrangement composed of polymer cover materials, such as ionomers, sur-

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rounding a rubber-like core. The golf ball materials have stiffness properties defined as the storage and loss moduli for compression (E'_{ball} , E''_{ball}) and storage and loss moduli for shear (G'_{ball} , G''_{ball}) that are strain (or load), strain rate (or time rate of loading), input frequency, and temperature dependent. The compression loss factor (η_E) and shear loss factor (η_G) (damping or energy loss mechanisms), which are defined as the ratio of loss modulus to the storage modulus, are also strain, strain rate, input frequency, and temperature dependent. The golf ball loss factors, or damping level, is on the order of 10–100 times larger than the damping level of a metallic golf club striking plate. Thus, during impact most of the energy is lost as a result of the large deformations, typically 0.05 to 0.50 inches, and deformation rates of the golf ball as opposed to the small deformations of the metallic striking plate of the golf club head, typically 0.025 to 0.050 inches.

By allowing the golf club head to flex and “cradle” the golf ball during impact, the contact region as well as contact time between the golf ball and the striking plate of the golf club head are increased, thus reducing the magnitude of the internal golf ball stresses as well as the rate of the stress build-up. This results in smaller golf ball deformations and lowers deformation rates, both of which produce much lower energy losses in the golf ball during impact. The static flexibility is inversely proportional to the striking plate stiffness, while the dynamic flexibility is inversely proportional to square of the striking plate bending natural frequency. In other words, a decrease in plate stiffness will cause the static flexibility to increase, while doubling the plate bending natural frequency will reduce dynamic flexibility to a level $\frac{1}{4}$ of the original striking plate. Increasing the static or dynamic flexibility can be accomplished via several different configurations for the golf club head: altering geometry of the face section; altering attachment of the striking plate to the club-head body; reducing the thickness of the striking plate; or through the innovative use of new structural materials having reduced material stiffness and/or increased material density. Material strength of the striking plate of the golf club head in conjunction with impact load from contact with the golf ball determines the minimum required thickness for the face section. The greater the available material strength, the thinner the striking plate can be, and thus greater the flexibility. So the material properties that control static and dynamic flexibility are decreased compression stiffness, increased density, and increased strength. The present invention specifies which face materials and static/dynamic flexibilities provide improved energy conservation during impact of the golf club head and the golf ball. Materials used in the face section of the golf club head constitute an additional important factor in determining performance characteristics of coefficient of restitution (COR), launch angle, spin rate and durability.

One object of the present invention is to improve impact efficiency between a golf club head and the golf ball.

Another object is to designate a range of material properties to increase the static flexibility, otherwise described as reduced bending stiffness, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

Another object is to designate a range of material properties to increase the dynamic flexibility, otherwise described as reduced bending natural frequency, of the striking plate of the golf club head. Any number of materials

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having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

A further object of the present invention is a wood-type golf club head having a face section of a first material and a body section of a second material.

Another object of the present invention is a wood-type golf club head having a face section of a metal material.

Another object of the present invention is a wood-type golf club head having a face section of a non-metal material.

Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of a golf club head of an embodiment of the present invention.

FIG. 2 is a front view of a golf club head showing a striking plate with a major cross-section dimensional width (W) and a minor cross-section dimensional height (H).

FIG. 3 shows a striking plate having an elliptical shape with a major and a minor cross-section dimensions (W) and (H), respectively, of an embodiment of the present invention.

FIG. 4 shows an elliptical plate with a pressure loading over a central circular region.

FIG. 5a shows the face section of the club head, of an embodiment of the present invention, prior to impact with the golf ball.

FIG. 5b shows deformation of the striking plate of the golf club head, of an embodiment of the present invention, during impact with the golf ball.

FIG. 5c shows an elliptical striking plate having a simply-supported edge constraint prior to impact with the golf ball.

FIG. 5d shows deformation of the elliptical striking plate of FIG. 5c during impact with the golf ball.

FIG. 5e shows an elliptical striking plate having a fixed edge constraint prior to impact with a golf ball.

FIG. 5f shows the elliptical striking plate of FIG. 5e during impact with the golf ball.

FIG. 6 is a plot of the normalized static and dynamic flexibility versus the face weight for a minimum weight design

FIG. 7 is a plot of the bending natural frequency versus the static flexibility for a minimum thickness design.

FIG. 8 is a plot of the static flexibility versus striking plate thickness for a large club head utilizing five different materials for the golf club striking plate.

FIG. 9 is a plot of the natural frequency versus striking plate thickness for a large club head utilizing five different golf club striking plate materials.

DETAILED DESCRIPTION

As shown in FIG. 1 a wood-type golf club head 10 comprises a face section 12, a rear section 14, a top section 16, a bottom section 18, a toe section 20, a heel section 22 and a hosel inlet 24 to accept a golf shaft (not shown). The golf club head 10 is a unitary structure which may be composed of two or more elements joined together to form the golf club head 10. The face section 12, also called a striking plate, is an impact surface for contacting a golf ball

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(not shown). Structural material for the golf club head 10 can be selected from metals and non-metals, with a face material exhibiting a maximum limit for face stiffness and natural frequency being a preferred embodiment.

The present invention is directed at a golf club head 10 having a striking plate 12 that makes use of materials to increase striking plate flexibility so that during impact less energy is lost, thereby increasing the energy transfer to the golf ball. This increased energy transfer to the golf ball will result in greater impact efficiency. The striking plate 12 is generally composed of a single piece of metal or nonmetallic material and may have a plurality of score-lines 13 thereon. The striking plate 12 may be cast with a body 26, or it may be attached through bonding or welding to the body 26. See FIGS. 1 and 2.

For explanation purposes, the striking plate 12 is treated as an elliptical shaped cross section having a uniform thickness, denoted as "t" in FIG. 4, that is subjected to a distributed load over a small circular region at the center of the striking plate 12. See FIGS. 3 and 4. Those skilled in the pertinent art will recognize that striking plates having other shapes, nonuniform thickness distribution, and force locations are within the scope and spirit of the present invention. The overall cross-section width is given by (W=2a), the overall cross-section height (H=2b), and the striking plate aspect ratio is defined as ($\alpha=b/a$). The impact load, resulting from impact of the golf ball with the golf club head 10, is treated as force of magnitude (F), acting with a pressure (q) over a circular region of radius (r_c) in the center of the elliptical plate so that

$$F = \int_0^{2\pi} \int_0^{r_c} q r dr d\theta.$$

Like other striking plates of the prior art, the striking plate 12 of the present invention is positioned between the top section 16 and bottom section 18. During impact with the golf ball, the striking plate 12 will deflect depending upon the connection to the top section 16 and the bottom section 18, see FIG. 5a-f. The two extreme limiting cases for all possible boundary attachment conditions are defined as "simply-supported" where the elliptical edge of the striking plate is constrained from translating but the edge is free to rotate, see FIG. 5c and 5d, and "fixed" or "clamped" where the elliptical edge is fixed from both translating and rotating, see FIG. 5e and 5f. The boundary attachment for the striking plate 12 to the body 26 of the club head 10 will fall between the two limiting cases since the top section 16 and bottom section 18 will provide some stiffening to the striking plate 12, but in general are very close to the simply supported condition. The calculated maximum stress in the striking plate as a result of the applied loading is

$$\sigma = \frac{3(1 + \nu)RF^*}{2\pi t^2}$$

where (F*) is the maximum load that includes the effects of design safety factors and the score-line 13 stress concentration factors, (t) is the plate thickness, (ν) is the material Poisson ratio, and (R) depends upon the plate geometry (a,b), load radius, material Poisson ratio, and edge support conditions. For golf club heads, the top section 16 and bottom section 18 provide some stiffening to the striking plate 12 edge, (R) will fall between the simply-supported edge and the fixed support, but for this invention it is very close to the simply-support edge condition;

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$$R_{\text{simply-sup port}} = \ln\left(\frac{b}{r_o}\right) + \frac{\nu}{(1+\nu)}(6.57 - 2.57\alpha)$$

$$R_{\text{fixed}} = \ln\left(\frac{2b}{r_o}\right) - .317\alpha - .376.$$

The minimum required thickness of the striking face based upon the applied loading is determined by setting the maximum stress to the allowable material yield stress (σ_{yield}) and solving;

$$t = \sqrt{\frac{3(1+\nu)RF^*}{2\pi\sigma_{\text{yield}}}}.$$

The minimum required striking plate thicknesses for two different materials (materials A and B) can be directly compared using Equation (IV), if one assumes that the impact forces, the plate geometry (W, H), and the edge boundary constraints are nearly the same. Writing the ratio of the minimum required thicknesses for two different materials is

$$\frac{t_A}{t_B} = \sqrt{\left(\frac{\sigma_{\text{yield-B}}}{\sigma_{\text{yield-A}}}\right)\left(\frac{1+\nu_A}{1+\nu_B}\right)},$$

where (t_A) and (t_B) are the minimum required thicknesses for plates composed of materials A and B, respectively, and ($\sigma_{\text{yield-A}}$, ν_A) and ($\sigma_{\text{yield-B}}$, ν_B) are the material properties of A and B, respectively. A weight ratio comparison of two minimum thickness striking plates is equal to

$$\frac{W_A}{W_B} = \frac{\rho_A t_A \pi ab}{\rho_B t_B \pi ab} = \frac{\rho_A}{\rho_B} \sqrt{\left(\frac{\sigma_{\text{yield-B}}}{\sigma_{\text{yield-A}}}\right)\left(\frac{1+\nu_A}{1+\nu_B}\right)},$$

where (ρ_A) and (ρ_B) are the densities of material A and B, respectively, and these plates have identical geometry (W, H), boundary constraints, and are designed to withstand the same load (F^*).

Static Flexibility

The calculated striking plate static flexibility (S), which is the inverse of the plate stiffness, is defined as the calculated center displacement of the striking plate 12 divided by the plate force (F^*) and is equal to:

$$S = \frac{b^2}{Et^3} P,$$

where (b) is half the height of the striking plate 12, (E) is Young's modulus and (P) depends upon the geometry and the support conditions of the elliptical plate. For golf heads, (P) will fall between the simply-supported and fixed edge conditions, but for this invention it falls very close to the simply-supported edge condition;

$$P_{\text{sharply-sub port}} = (0.76 - 0.18\alpha)$$

$$P_{\text{fixed}} = (0.326 - 0.104\alpha)$$

Thus, increased striking plate flexibility can be accomplished by increasing the striking plate height (b), decreasing the Young's modulus (E), also described as material stiffness, or by reducing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV)

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into (VII), results in the static flexibility having a minimum allowable plate thickness;

$$S = \left[\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{\frac{3}{2}} \right] \left[Pb^2 \left(\frac{2\pi}{3RF^*} \right)^{\frac{3}{2}} \right],$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (P, R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are the same for two different designs (second bracketed term of Equation IX), then to maximize the static flexibility, one needs to select a material having the largest ratio of:

$$\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{\frac{3}{2}}.$$

The static flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (IX) as a ratio

$$\frac{S_A}{S_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{\sigma_{\text{yield-A}}}{\sigma_{\text{yield-B}}} \right)^{\frac{3}{2}} \left(\frac{1+\nu_B}{1+\nu_A} \right)^{\frac{3}{2}},$$

where (S_A) and (S_B) are the static flexibilities of a plate having a minimum plate thickness for materials A and B, respectively and (E_A) and (E_B) are the material stiffnesses for materials A and B, respectively.

Bending Natural Frequency

The calculated bending natural frequency (ω), or referred to simply as natural frequency, having units of cycles/second (Hz), for the elliptical striking plate is given by;

$$\omega(\text{Hz}) = \frac{\lambda t}{b^2} \sqrt{\frac{Eg}{\rho(1-\nu^2)}}$$

where (ν) is the material Poisson ratio, (b) is half the height of the striking plate 12, (ρ) is the material weight density, (g) is the gravitational constant (32.2 ft/sec²), and (λ) depends upon the geometry and the support conditions of the elliptical plate, as well as the desired vibration mode. For golf club heads, (λ) will fall between the two limiting edge support values, simply-support and fixed, but for this invention it is very close to the simply-support condition;

$$\lambda_{\text{simply-sup port}} = .124\sqrt{1 + .21\alpha + 2.37\alpha^2 - 3.03\alpha^3 + 2.7\alpha^4}$$

$$\lambda_{\text{fixed}} = .2877\sqrt{1 + 2/3\alpha^2 + \alpha^4}.$$

The bending natural frequency can be minimized by increasing the striking plate 12 height (2b) or aspect ratio (α), increasing the material density (ρ), decreasing the material stiffness (E), or decreasing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV) into (XII), results in the natural frequency having a minimum allowable plate thickness;

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$$\omega = \left[\sqrt{\frac{E}{\sigma_{yield}\rho(1-\nu)}} \right] \left[\frac{\lambda}{b^2} \sqrt{\frac{3gRF^*}{2\pi}} \right]$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are the fixed (second bracketed term of Equation XIV), then to minimize the natural frequency, one needs to select a material having the smallest of:

$$\frac{E}{\sigma_{yield}\rho(1-\nu)}$$

The natural frequency of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XIV) as a ratio

$$\frac{\omega_A}{\omega_B} = \sqrt{\frac{E_A}{E_B} \left(\frac{\sigma_{yield-B}}{\sigma_{yield-A}} \right) \left(\frac{\rho_B}{\rho_A} \right) \left(\frac{1-\nu_B}{1-\nu_A} \right)},$$

where (ω_A) and (ω_B) are the natural frequencies of a striking plate having a minimum plate thickness for materials A and B.

A golf club head has a large number of natural frequencies, where some involve the vibratory motion that characterize the striking plate, others involve motion that characterize the top plate or bottom plate, and still others involve the combined motion of the striking plate and other parts of the club head. The natural frequencies that are of concern in the present invention involve the full or partial vibratory motion of the striking plate. Thus, to experimentally measure these frequencies, one needs to excite the striking plate as well as record its response. A noncontacting excitation and response system is preferred to insure that added mass or stiffness effects do not artificially alter the results. In our experimental studies, the striking plate was excited using either an impact hammer (PCB Inc. of Buffalo, N.Y., model 068, series 291; or Kistler Instrument Corp. of Amherst, N.Y., model 9722A500) or an acoustical funnel-cone speaker, where the speaker is driven with broad-band white random noise between 1000–10,000 Hz. The velocity time history (response) is measured using a laser velocimeter (Polytec PI GmbH of Waldbronn, Germany, model OFV-303 or PSV-300; or Ometron Inc. of London, England, model VPI-4000). The recorded excitation and response time histories are processed using a two-channel spectrum analyzer (Hewlett Packard of Palo Alto, Calif.) to determine the frequency content of the response signal divided by the excitation signal. The spectrum analyzer has input/output windowing features and anti-aliasing filters to eliminate processing errors. The test is repeated a minimum of 10 times and the data is averaged to minimize the effects of uncorrelated noise. Thus the coherence was found to be greater than 0.98 at all measured natural frequencies. The tests are repeated using numerous excitation and response locations on the striking plate to insure that the lowest striking plate dominated natural frequencies are recorded.

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Dynamic Flexibility

The dynamic flexibility (D) for the striking plate is given by

$$D = \frac{1}{m_e(2\pi\omega)^2},$$

where, (ω) is the striking plate natural frequency, and (m_e) is the effective face mass that contributes to the dynamic response during impact:

$$m_e = \beta \frac{\rho}{g} \pi t a b = \beta \frac{\rho}{g} \pi t \frac{b^2}{\alpha}.$$

Here (β) is defined between (0) and (1), where (0) is associated with no face mass contributing to the dynamic response and (1) having all of the face mass contributing to the response. For golf clubs, ($0.15 < \beta < 0.35$). Writing the dynamic flexibility by substituting Equations (XIV) and (XVIII) into (XVII):

$$D = \frac{b^2}{E t^3} \left(\frac{\alpha(1-\nu^2)}{4\beta\pi^3\lambda^2} \right).$$

The striking plate dynamic flexibility can be increased by enlarging the plate depth (b) or aspect ratio (α), decreasing the material stiffness (E), or decreasing the plate thickness (t). Clearly the greatest increase in (D) can be found by changing the thickness (t), followed by changing the face height (2b). But, the plate thickness can only be reduced up to the allowable value of Equation (IV). Thus, the maximum dynamic flexibility (D) for a given plate geometry and applied load is calculated by substituting the minimum allowable thickness Equation (IV) into (XIX);

$$D = \left[\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^2 \right]^{\frac{3}{2}} \left[\left(\frac{ab^2}{4\beta\pi^3\lambda^2} \right) \left(\frac{2\pi}{3RF^*} \right)^{\frac{3}{2}} \right]$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (λ , R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are constant (second bracketed term of Equation XX), then to maximize the dynamic flexibility (D), one needs to select a material having the largest ratio of:

$$\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^2$$

The dynamic flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XX) as a ratio

$$\frac{D_A}{D_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{1-\nu_A^2}{1-\nu_B^2} \right) \left(\frac{\sigma_{yield-A}}{\sigma_{yield-B}} \right)^2 \left(\frac{1+\nu_B}{1+\nu_A} \right)^2,$$

where (D_A) and (D_B) are the maximum dynamic flexibilities of a plate having a minimum plate thickness for materials A and B, respectively.

For wood-type golf clubs the following geometry and force properties are typical (a=1.4–1.65 inch, b=0.7–1.0 inch, t=0.14–0.25 inch, F*=2000–15,000 lbs). In Table 1, current metal golf club head material properties are given

along with five different golf club head property ratios. These five different ratios include: minimum required striking plate thickness (Eq. V), resulting striking plate weight (Eq. VI), static flexibility (Eq. XI), bending natural frequency (Eq. XVI), and dynamic flexibility (Eq. XXII), where the baseline (B) material is taken as (17-4) Stainless Steel. These ratios provide a comparison of striking plates that have identical elliptical geometry, edge attachment, and load capacity, but are composed of different materials and thus will have different minimum striking plate thicknesses. A normalized comparison of the static flexibility and dynamic flexibility to face weight is presented in FIG. 6, where all results are normalized to an equivalent (17-4) Stainless Steel striking plate. In FIG. 6, it is clear that the amorphous alloy striking plate and maraging striking plate offer (4.8) and (2.5) times more flexibility and lower face weight than stainless steel as a result of their high strength, while the titanium alloy striking plate offers 50% more flexibility and lower face weight as a result of significantly lower modulus, but that the aluminum alloy striking plate results in lower flexibility as a result of its lower strength. These increases in flexibility lead to reduced impact energy losses, which in turn lead to greater golf ball flight velocities. In FIG. 7, a comparison of normalized face natural frequency versus static flexibility is presented, where a corre-

between 0.100 and 0.070 inches. The Aluminum 7075-T6 striking plate is thickest because of its low strength, but it is the lightest as a result of its low density. In a preferred embodiment the striking plate of aluminum alloy has a maximum thickness of less than 0.200 inches, and more preferably between 0.200 and 0.070 inches. The striking plates composed of an amorphous alloy, Maraging 280 steel, and the 6-4 Titanium all have static and dynamic flexibilities much greater than the 17-4 Stainless Steel striking plate (480%, 240% and 150%), while the aluminum alloy striking plate has a 12% lower flexibility as a result of its large thickness. Finally, the striking plates composed of amorphous alloy and maraging steel have bending natural frequencies which are 41% and 27% lower, respectively, than the 17-4 Stainless Steel striking plate, whereas the titanium alloy striking plate is nearly the same as the stainless steel, while the aluminum alloy striking plate is 50% greater as a result of an increased thickness and low density.

It should be further pointed out, that most golf club designers use the striking plate weight savings to further increase the size of the striking plate (i.e. oversize titanium drivers) and thus further increase its static and dynamic flexibility.

Table 1: Typical Material Properties used in Golf Club Faces and Comparison Ratios

TABLE 1

Typical Material Properties used in Golf Club Faces and Comparison Ratios									
Material (i)	E 10 ⁶ lb/in ²	v	σ _{yield} 10 ³ lb/in ²	ρ lb/in ³	t _i /t _{steel}	W _i /W _{steel}	S _i /S _{steel}	ω _i /ω _{steel}	D _i /D _{steel}
Stainless Steel(17-4)	29.0	.27	150	.276	1.00	1.00	1.00	1.00	1.00
Aluminum (7075-T6)	10.4	.33	73	.101	1.47	0.54	0.88	1.48	0.85
Titanium (Ti 6-4)	16.0	.31	138	.160	1.06	0.61	1.53	1.05	1.49
Maraging 280 Steel	26.5	.31	262	.285	0.77	0.79	2.41	0.73	2.35
Amorphous Alloy	13.3	.30	260	.220	0.77	0.61	4.80	0.59	4.72

lation exists between measured natural frequency and static flexibility, and thus natural frequency can be used as a simple nondestructive measurement technique for assessing the magnitude of the static and dynamic flexibility. It is observed that the amorphous alloy and maraging steel striking plates have a lower natural frequency and greater flexibility than other materials in FIG. 7 because of their high strength and density. The titanium alloy striking plate and aluminum alloy striking plate have natural frequencies higher than all the other materials in FIG. 7 because of their low density.

A detailed inspection of Table 1 reveals that striking plates composed of Maraging 280 steel or the amorphous alloy are 23% thinner than the 17-4 Stainless Steel striking plate, which is a direct result of higher strength of these materials. In a preferred embodiment the striking plate of stainless steel has a maximum thickness of less than 0.130 inches, and more preferably between 0.130 and 0.070 inches, while both the maraging steel and amorphous alloy have a striking plate thickness of less than 0.100 inches, and more preferably

As a second example, consider a very large oversized driver head similar to a Callaway Golf® Biggest Big Bertha driver that is fabricated with different material striking plates. The geometry values are defined as (a=1.65 inch, b32 0.875 inch, α=0.530). In order to produce striking plate flexibility levels greater than found in any current club-head: (1) the striking plate has no scorelines, thus (F*=2500 lbs) with a radius (r_o=0.50 inch), and (2) the edge attachment condition is nearly simply-supported so that (P=0.664, A=0.1538). Constructing the striking plate out of Titanium (Ti 6-4), leads to (R=1.792) and a minimum required face thickness of (t=0.143 inch). Including score-line stress concentration factors will simply increase (F*), thus increasing the required face thickness (t) and bending natural frequency, and decreasing the flexibility. The calculated weight is (W=0.103 lb), the static flexibility is (S=1.10×10⁻⁵ in/lb), the natural frequency (ω=5920 Hz), and the dynamic flexibility (D=1.08×10⁻⁵ in/lb), where it was assumed (β=0.25). The calculated head natural frequency of 5920 Hz is within 2% of the experimentally measured value

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of 6040 Hz on an actual experimental hybrid golf club head. The maximum displacement of the striking plate is found by multiplying the static flexibility and the effective force (F*), thus ($\Delta=0.0275$ inch). Hybrid golf club heads having different material striking face plates are presented in Table 2, where the striking plates have minimum allowable face thicknesses. In FIGS. 8 and 9, the variation of the static flexibility and natural frequency with striking plate thickness is presented for the five different metals, where the symbol (o) is used to represent the minimum allowable thickness for a assumed applied load ($F^*=2500$ lbs). Clearly, if the applied load were increased then the minimum allowable thicknesses would increase, where the symbols would just move to the right along the appropriate curve. Thus lowering the flexibility and increasing the natural frequency.

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8500 Hz and 2800 Hz. For the titanium alloy striking plate 12, the natural frequency is below 5900 Hz, and in a more preferred embodiment the natural frequency is between 5900 Hz and 2800 Hz. For the stainless steel striking plate 12, the natural frequency is below 5400 Hz, and in a more preferred embodiment the natural frequency is between 5400 Hz and 2800 Hz. For the maraging steel striking plate 12, the natural frequency is below 6000 Hz, and in a more preferred embodiment the natural frequency is between 6000 Hz and 2800 Hz. For the amorphous alloy striking plate 12, the natural frequency is below 5500 Hz, and in a more preferred embodiment the natural frequency is between 5500 Hz and 2800 Hz.

TABLE 2

Calculated Striking Plate Properties for a Hybrid Oversized Driver Golf Club Head without scorelines (a = 1.65, b = .875, α = .530, F* = 2500 lb, r_0 = 0.5, P = 0.664, λ = .154, β = 0.25).											
Material (i)	E 10^6 lb/in ²	ν	σ_{yield} 10^3 lb/in ²	ρ lb/in ³	R	T Inch	W lb	S 10^{-5} in/lb	Δ inch	ω inch	D 10^{-5} in/lb
Stainless Steel(17-4)	29.0	.27	150	.276	1.67	.130	.162	.803	.020	5458	.809
Aluminum (7075-T6)	10.4	.33	73	.101	1.85	.200	.092	.605	.015	8520	.586
Titanium (Ti 6-4)	16.0	.31	138	.160	1.79	.142	.103	1.10	.027	5920	.808
Maraging 280 Steel	26.5	.31	262	.285	1.79	.103	.134	1.74	.043	4143	1.71
Amorphous Alloy	13.3	.30	260	.220	1.76	.102	.102	3.55	.089	3401	3.51

Moreover, if a higher strength version of an alloy were used, then the symbol would follow the curve to the left and thus increase the flexibility and lower natural frequency. It is observed that the greatest flexibility occurs for maraging steel and the amorphous alloy, which has the thinnest striking plates and lowest natural frequencies.

It is known through experimental testing, that currently available driver golf club heads have striking-face natural frequencies greater than 4500 Hz. Moreover, the only commercially available golf club head with an amorphous alloy striking plate (commercial name: Liquid Metal™) has a fundamental striking plate natural frequency of 5850 Hz. Thus, the striking plates on these club heads are not optimized for maximum flexibility. They do not have a minimum thickness striking plate, a large aspect ratio, or an edge support that simulates the simply supported constraint. From Equation XVII, the dynamic flexibility is inversely proportional to the square of the natural frequency, thus these heads have a flexibility that is much lower and a face thickness that is much greater than the optimized minimum values presented in the previous example (i.e. their values on FIGS. 8 and 9 would be to the far right of the minimum allowable thickness). In a preferred embodiment of the present invention, the material of striking plate 12 has a natural frequency of less than 4500 Hz, in a more preferred embodiment the striking plate 12 natural frequency is between 4500 Hz and 2800 Hz. For the aluminum alloy striking plate 12, the natural frequency is below 8500 Hz, and in a more preferred embodiment the natural frequency is between

Although the above description is for wood-type golf club heads having an elliptical face section, the present invention is not limited to such an embodiment. Also included within the bounds of the present invention are iron type golf club heads and golf club heads with α values approaching 1.0.

The golf club head 10 is a fairway wood or a driver. The golf club head 10 has a body 26, excluding the striking plate 12, that is preferably composed of a metal material such as titanium, titanium alloy, stainless steel, or the like, and is most preferably composed of a forged titanium material. However, the body 26, or a portion of the body 26, may be composed of a graphite composite material or the like. The body 26 preferably has a large volume, most preferably greater than 300 cubic centimeters, more preferably 300 cubic centimeters to 450 cubic centimeters, even more preferably 350 cubic centimeters to 400 cubic centimeters, and is most preferably 385 cubic centimeters for a body composed of titanium, or titanium alloy. However, a body 26 composed of stainless steel may have a volume range of 200 cubic centimeters to 325 cubic centimeters, and a body 26 composed of a composite material (such as plies of continuous carbon fiber pre-preg material) may have a volume of 325 cubic centimeters to 600 cubic centimeters. The body 26 preferably weighs no more than 215 grams, and most preferably weighs between 180 and 205 grams. The body 26 has a hollow interior.

From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the

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present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims. preferably composed of a forged titanium material. However, the body 26, or a portion of the body 26, may be composed of a graphite composite material or the like. The body 26 preferably has a large volume, most preferably greater than 300 cubic centimeters, more preferably 300 cubic centimeters to 450 cubic centimeters, even more preferably 350 cubic centimeters to 400 cubic centimeters, and is most preferably 385 cubic centimeters for a body composed of titanium, or titanium alloy. However, a body 26 composed of stainless steel may have a volume range of 200 cubic centimeters to 325 cubic centimeters, and a body 26 composed of a composite material (such as plies of continuous carbon fiber pre-preg material) may have a volume of 325 cubic centimeters to 600 cubic centimeters. The body 26 preferably weighs no more than 215 grams, and most preferably weighs between 180 and 205 grams. The body 26 has a hollow interior.

From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

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I claim as my invention:

1. A wood-type golf club head comprising:
a body having a top region, a bottom region, a rear region and an open front;
a striking plate disposed in the open front of the body, the striking plate composed of a titanium alloy material and having a thickness less than 0.200 inch and greater than 0.070 inch, the striking plate having a natural frequency of less than 4500 Hz and greater than 2800 Hz.

2. The wood-type golf club head according to claim 1 wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

3. The wood-type golf club head according to claim 1 wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

4. The wood-type golf club head according to claim 1 wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

5. A wood-type golf club head comprising:
a body having a top region, a bottom region, a rear region and an open front;
a striking plate disposed in the open front of the body, the striking plate composed of a titanium alloy material and having a thickness less than 0.140 inch, the striking plate having a natural frequency of less than 8500 Hz and greater than 2800 Hz.

6. A wood-type golf club head comprising:
a body having a striking plate, the striking plate composed of a titanium alloy material and having a thickness less than 0.200 inch and greater than 0.070 inch, the striking plate having a natural frequency of less than 4000 Hz and greater than 2800 Hz.

7. A wood-type golf club head comprising:
a body having a top region, a bottom region, a rear region and an open front, the body composed of a non-metallic material;
a striking plate disposed in the open front of the body, the striking plate composed of a titanium alloy material and having a thickness less than 0.140 inch, the striking plate having a natural frequency of less than 8500 Hz and greater than 2800 Hz.

* * * * *

Exhibit D

(12) **United States Patent**
Kosmatka

(10) **Patent No.:** **US 6,685,576 B2**
(45) **Date of Patent:** ***Feb. 3, 2004**

(54) **GOLF CLUB HEAD HAVING A STRIKING FACE WITH IMPROVED IMPACT EFFICIENCY**

(58) **Field of Search** 473/324, 332, 473/349, 350, 329, 342, 345, 346, 290, 291

(75) **Inventor:** **John B. Kosmatka**, Encinitas, CA (US)

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(73) **Assignee:** **Callaway Golf Company**, Carlsbad, CA (US)

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(*) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1 day.

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(57) **ABSTRACT**

Related U.S. Application Data

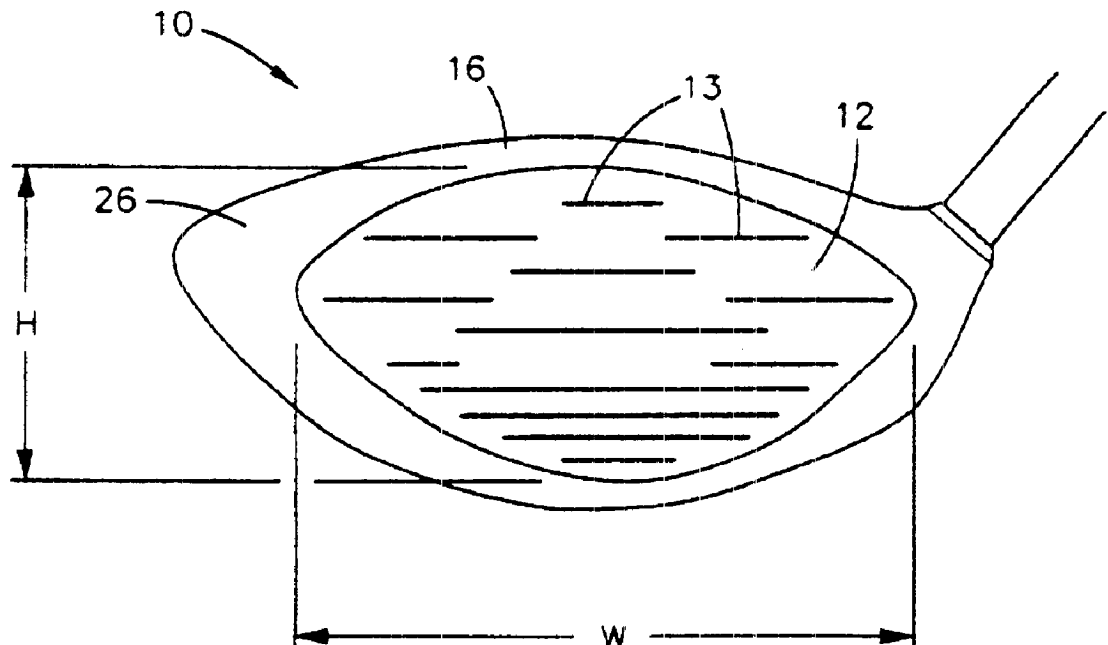
(63) Continuation of application No. 10/065,690, filed on Nov. 8, 2002, which is a continuation of application No. 09/683,799, filed on Feb. 15, 2002, now Pat. No. 6,478,692, which is a continuation-in-part of application No. 09/525,216, filed on Mar. 15, 2000, now Pat. No. 6,348,015.

A compliant golf club head permits a more efficient impact between a golf ball and the golf club head. Material and geometry constraints of a striking plate of the golf club head can reduce energy losses caused by large strain and strain rate values of the golf ball, these constraints on the striking plate yield a measure of the impact efficiency of the golf club head. Designating a required natural frequency range of the striking plate provides improved impact efficiency between the golf ball the golf club head.

(51) **Int. Cl.⁷** **A63B 53/04**

(52) **U.S. Cl.** **473/342; 473/329; 473/345; 473/349; 473/350**

7 Claims, 7 Drawing Sheets



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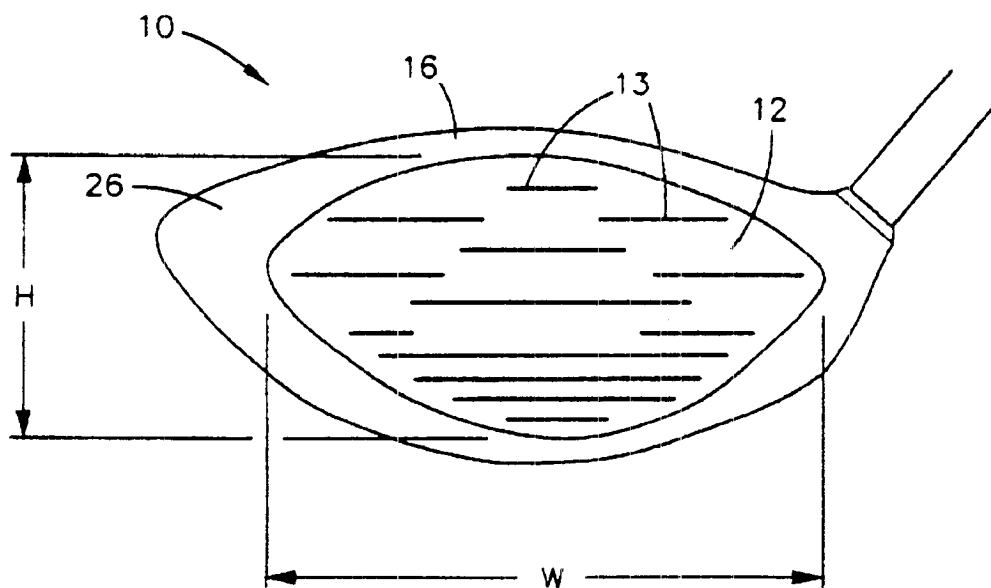
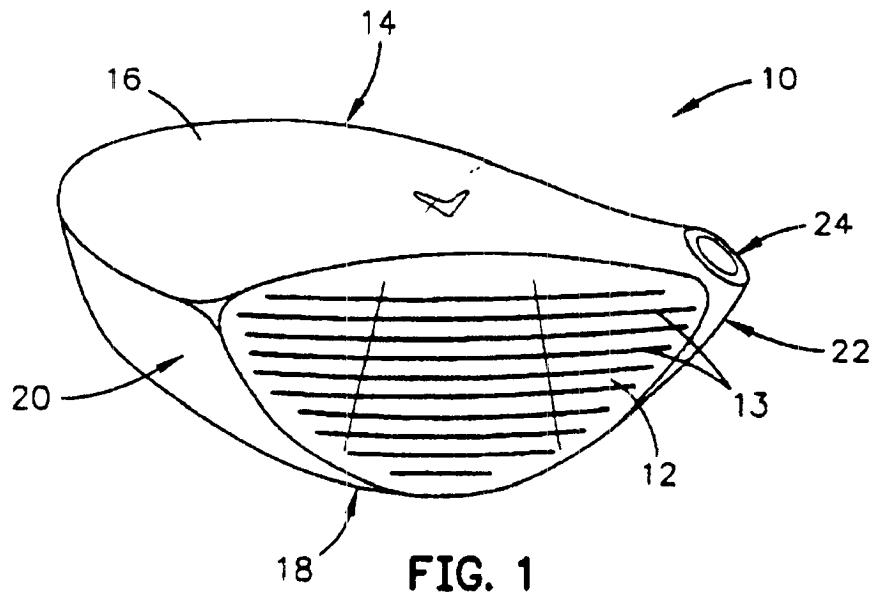


FIG. 2

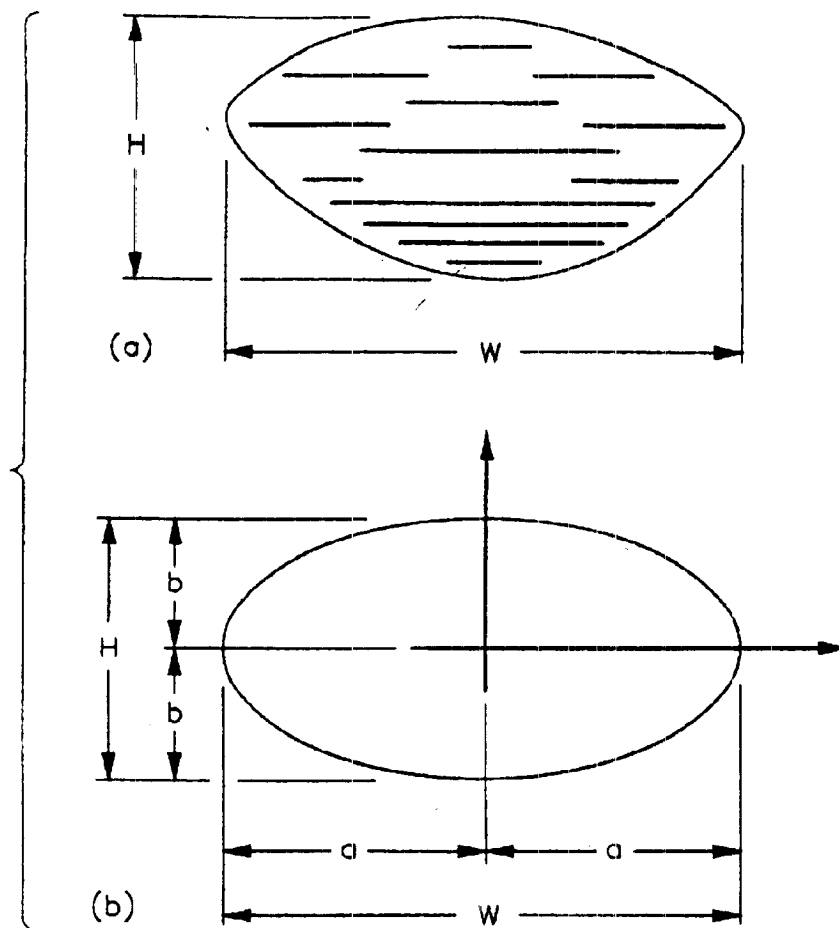


FIG. 3

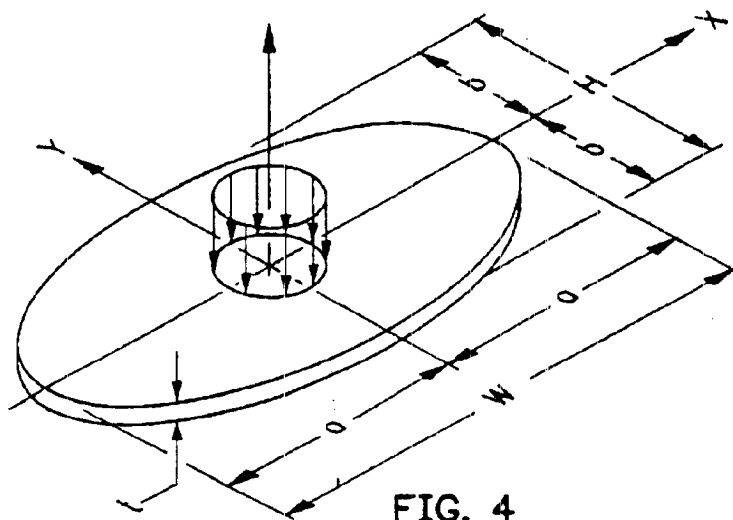


FIG. 4

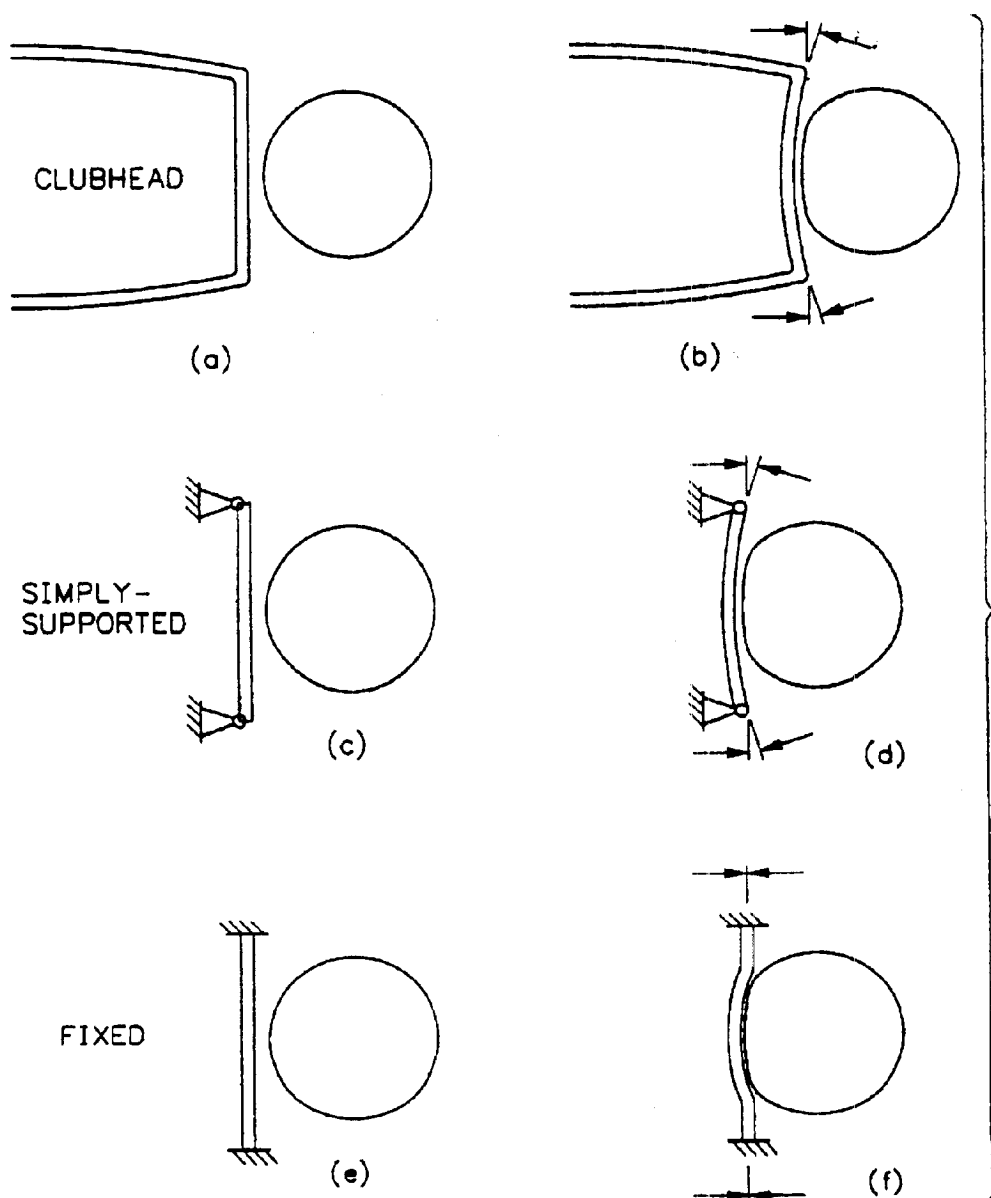


FIG. 5

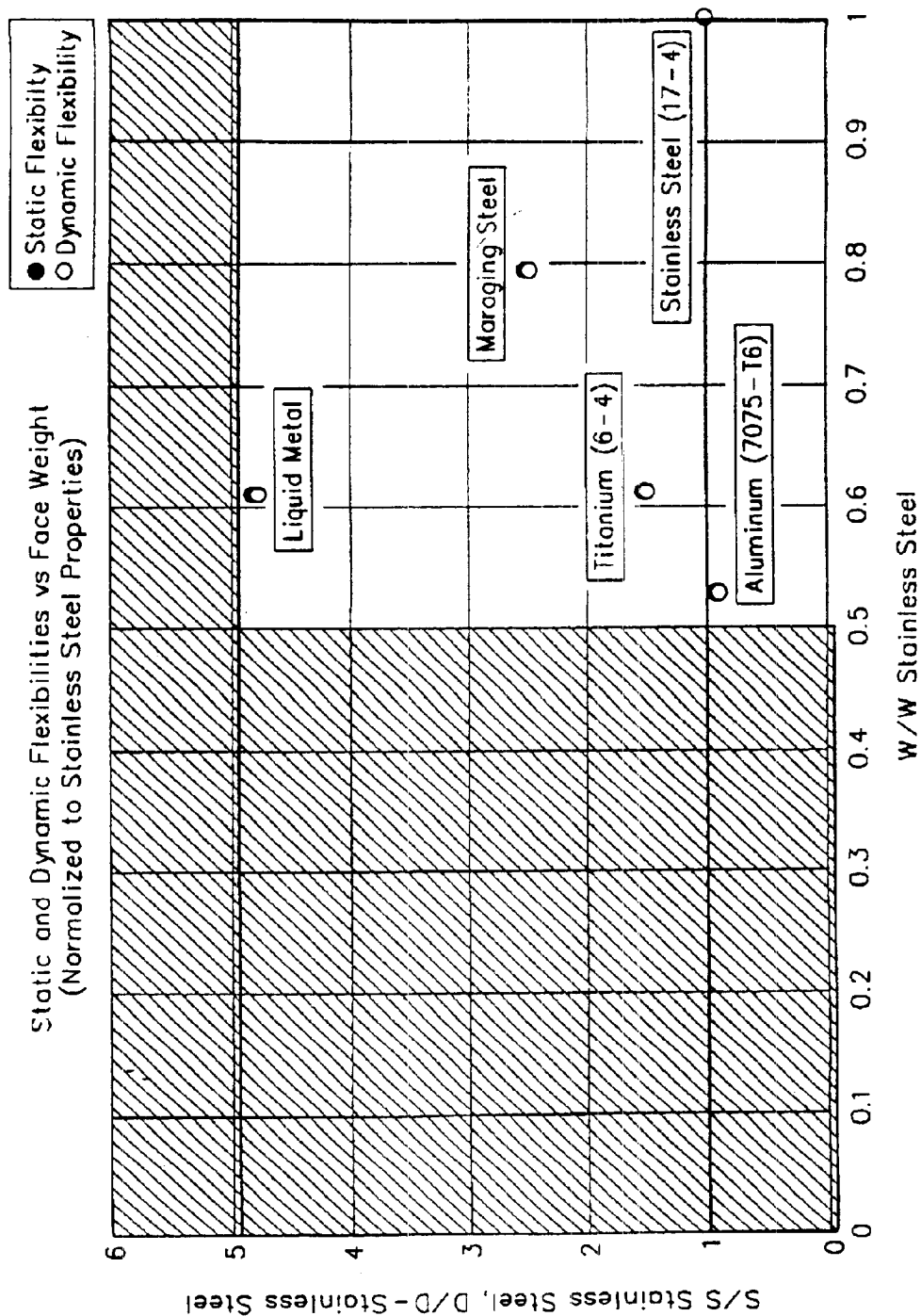


FIG. 6

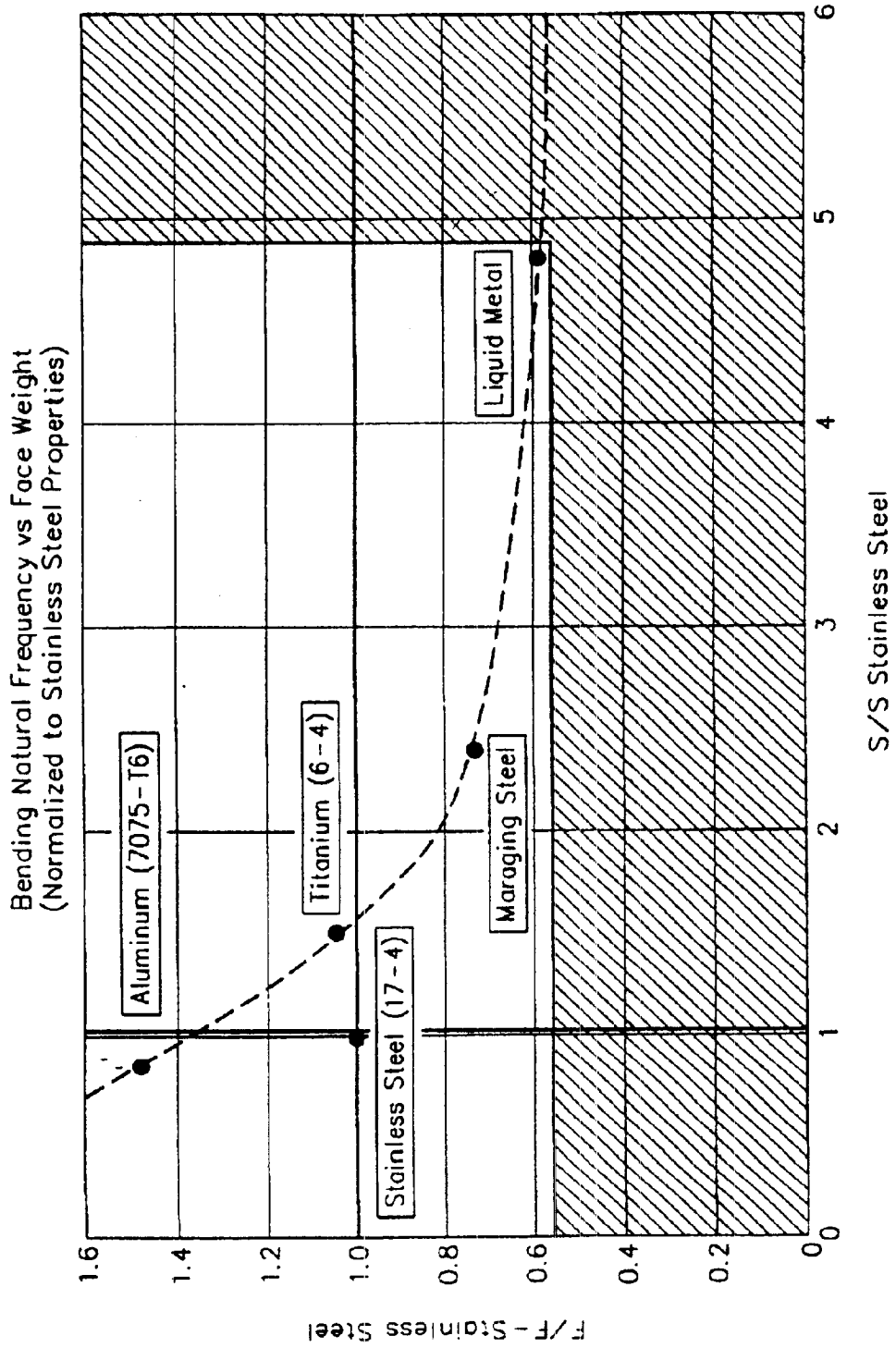


FIG. 7

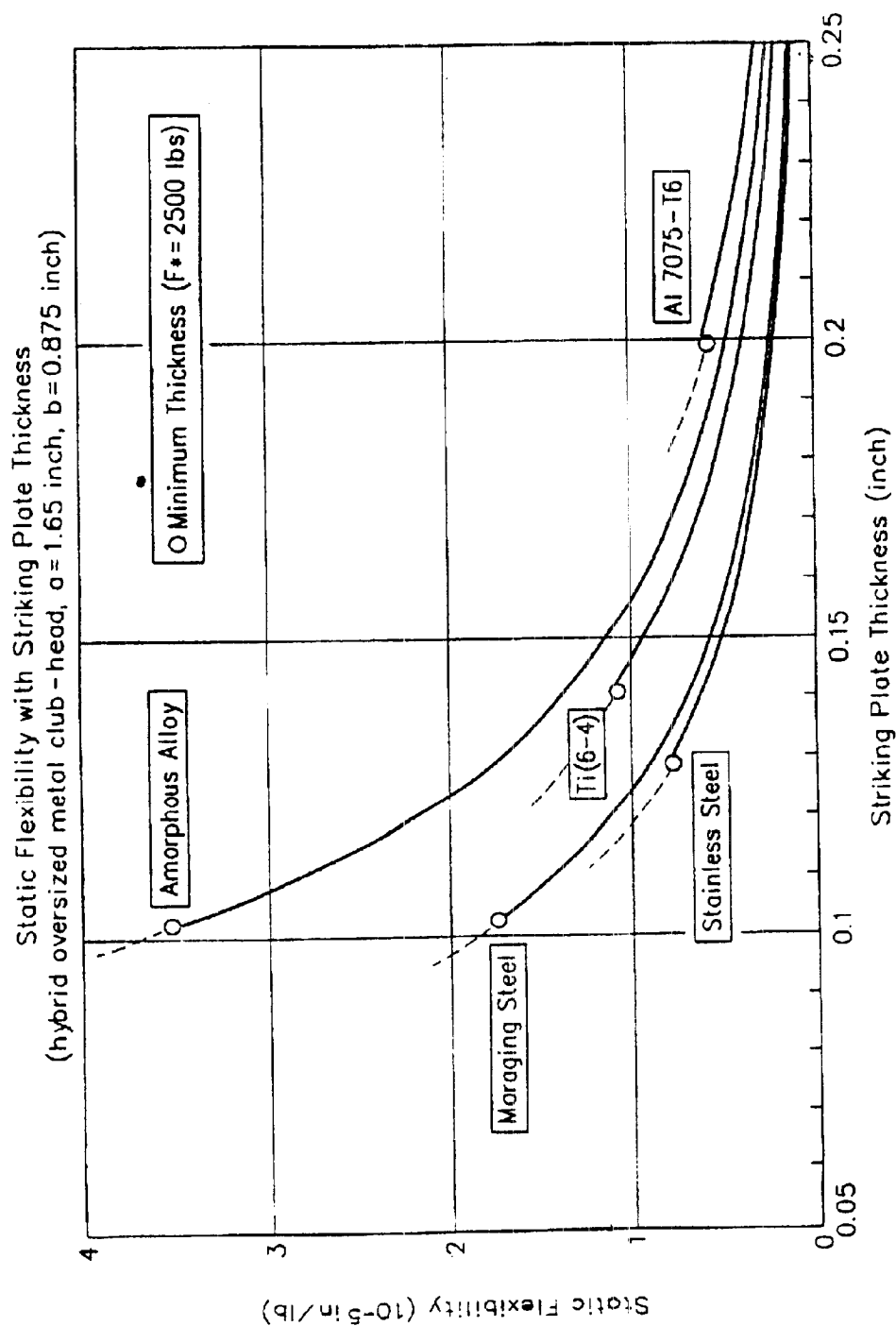


FIG. 8

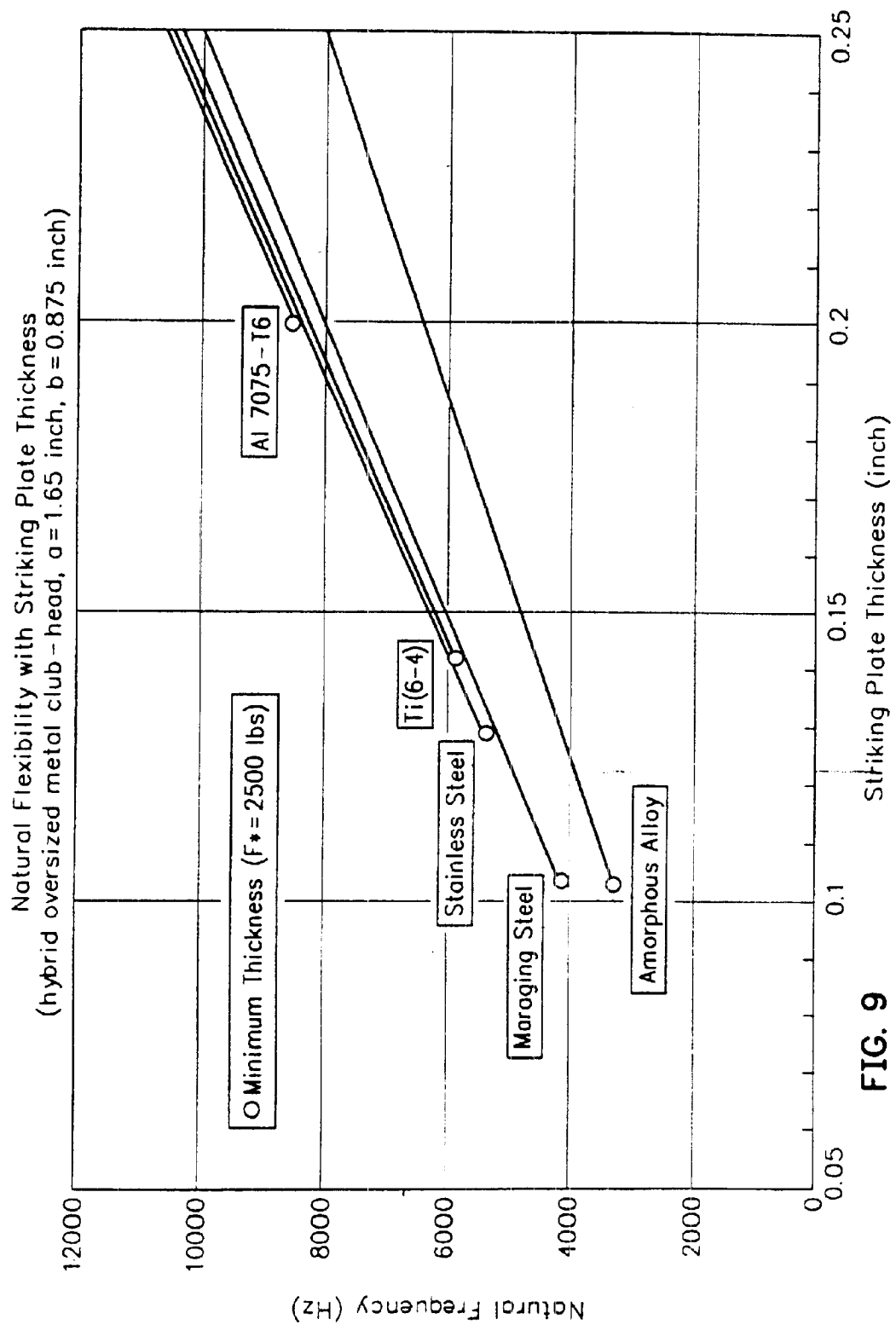


FIG. 9

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GOLF CLUB HEAD HAVING A STRIKING FACE WITH IMPROVED IMPACT EFFICIENCY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 10/065,690, filed on Nov. 8, 2002, which is a application of U.S. patent application Ser. No. 09/683,799, filed on Feb. 15, 2002, now U.S. Pat. No. 6,478,692 issued on Nov. 15, 2002 which is a continuation-in-part application of U.S. patent application Ser. No. 09/525,216 filed on Mar. 14, 2000, now U.S. Pat. No. 6,348,015 issued on Feb. 19, 2002.

FEDERAL RESEARCH STATEMENT

[Not Applicable]

BACKGROUND OF INVENTION

1. Field of the Invention

The present invention relates to a golf club head. More specifically, the present invention relates to a face section of a golf club head to reduce energy losses when impacting a golf ball.

2. Description of the Related Art

Technical innovation in the material, construction and performance of golf clubs has resulted in a variety of new products. The advent of metals as a structural material has largely replaced natural wood for wood-type golf club heads, and is but one example of this technical innovation resulting in a major change in the golf industry. In conjunction with such major changes are smaller scale refinements to likewise achieve dramatic results in golf club performance. For example, the metals comprising the structural elements of a golf club head have distinct requirements according to location in the golf club head. A sole or bottom section of the golf club head should be capable of withstanding high frictional forces for contacting the ground. A crown or top section should be lightweight to maintain a low center of gravity. A front or face of the golf club head should exhibit high strength and durability to withstand repeated impact with a golf ball. While various metals and composites are known for use in the face, several problems arise from the use of existing materials.

Existing golf club face materials such as stainless steel exhibit desired high strength and durability but incur large energy losses during impact with the golf ball as a result of large ball deformations. An improvement in impact energy conservation, in conjunction with proper golf ball launch parameters, is a design goal for golf club manufacturers. The problem still exists of identifying a combination of material properties exhibiting improvements in conservation of impact energy during impact with the golf ball.

SUMMARY OF INVENTION

When a golf club head strikes a golf ball, large impact forces are produced that load a face section, also called a striking plate, of the golf club head. Most of the energy is transferred from the golf club head to the golf ball; however, some energy is lost as a result of the impact. The present invention comprises a golf club striking plate material and geometry having a unique combination of material properties for improved energy efficiency during impact with the golf ball.

The golf ball is typically a core-shell arrangement composed of polymer cover materials, such as ionomers, sur-

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rounding a rubber-like core. The golf ball materials have stiffness properties defined as the storage and loss moduli for compression (E'_{ball} , E''_{ball}) and storage and loss moduli for shear (G'_{ball} , G''_{ball}) that are strain (or load), strain rate (or time rate of loading), input frequency, and temperature dependent. The compression loss factor ($\tan \delta_c$) and shear loss factor ($\tan \delta_s$) (damping or energy loss mechanisms), which are defined as the ratio of loss modulus to the storage modulus, are also strain, strain rate, input frequency, and temperature dependent. The golf ball loss factors, or damping level, is on the order of 10–100 times larger than the damping level of a metallic golf club striking plate. Thus, during impact most of the energy is lost as a result of the large deformations, typically 0.05 to 0.50 inches, and deformation rates of the golf ball as opposed to the small deformations of the metallic striking plate of the golf club head, typically 0.025 to 0.050 inches.

By allowing the golf club head to flex and “cradle” the golf ball during impact, the contact region as well as contact time between the golf ball and the striking plate of the golf club head are increased, thus reducing the magnitude of the internal golf ball stresses as well as the rate of the stress build-up. This results in smaller golf ball deformations and lowers deformation rates, both of which produce much lower energy losses in the golf ball during impact. The static flexibility is inversely proportional to the striking plate stiffness, while the dynamic flexibility is inversely proportional to square of the striking plate bending natural frequency. In other words, a decrease in plate stiffness will cause the static flexibility to increase, while doubling the plate bending natural frequency will reduce dynamic flexibility to a level $\frac{1}{4}$ of the original striking plate. Increasing the static or dynamic flexibility can be accomplished via several different configurations for the golf club head: altering geometry of the face section; altering attachment of the striking plate to the club-head body; reducing the thickness of the striking plate; or through the innovative use of new structural materials having reduced material stiffness and/or increased material density. Material strength of the striking plate of the golf club head in conjunction with impact load from contact with the golf ball determines the minimum required thickness for the face section. The greater the available material strength, the thinner the striking plate can be, and thus greater the flexibility. So the material properties that control static and dynamic flexibility are decreased compression stiffness, increased density, and increased strength. The present invention specifies which face materials and static/dynamic flexibilities provide improved energy conservation during impact of the golf club head and the golf ball. Materials used in the face section of the golf club head constitute an additional important factor in determining performance characteristics of coefficient of restitution (COR), launch angle, spin rate and durability.

One object of the present invention is to improve impact efficiency between a golf club head and the golf ball.

Another object is to designate a range of material properties to increase the static flexibility, otherwise described as reduced bending stiffness, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

Another object is to designate a range of material properties to increase the dynamic flexibility, otherwise described as reduced bending natural frequency, of the striking plate of the golf club head. Any number of materials

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having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

A further object of the present invention is a wood-type golf club head having a face section of a first material and a body section of a second material.

Another object of the present invention is a wood-type golf club head having a face section of a metal material.

Another object of the present invention is a wood-type golf club head having a face section of a non-metal material.

Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of a golf club head of an embodiment of the present invention.

FIG. 2 is a front view of a golf club head showing a striking plate with a major cross-section dimensional width (W) and a minor cross-section dimensional height (H).

FIG. 3 shows a striking plate having an elliptical shape with a major and a minor cross-section dimensions (W) and (H), respectively, of an embodiment of the present invention.

FIG. 4 shows an elliptical plate with a pressure loading over a central circular region.

FIG. 5a shows the face section of the club head, of an embodiment of the present invention, prior to impact with the golf ball.

FIG. 5b shows deformation of the striking plate of the golf club head, of an embodiment of the present invention, during impact with the golf ball.

FIG. 5c shows an elliptical striking plate having a simply-supported edge constraint prior to impact with the golf ball.

FIG. 5d shows deformation of the elliptical striking plate of FIG. 5c during impact with the golf ball.

FIG. 5e shows an elliptical striking plate having a fixed edge constraint prior to impact with a golf ball.

FIG. 5f shows the elliptical striking plate of FIG. 5e during impact with the golf ball.

FIG. 6 is a plot of the normalized static and dynamic flexibility versus the face weight for a minimum weight design.

FIG. 7 is a plot of the bending natural frequency versus the static flexibility for a minimum thickness design.

FIG. 8 is a plot of the static flexibility versus striking plate thickness for a large club head utilizing five

FIG. 9 is a plot of the natural frequency versus striking plate thickness for a large club head utilizing five different golf club striking plate materials.

DETAILED DESCRIPTION

As shown in FIG. 1 a wood-type golf club head 10 comprises a face section 12, a rear section 14, a top section 16, a bottom section 18, a toe section 20, a heel section 22 and a hosel inlet 24 to accept a golf shaft (not shown). The golf club head 10 is a unitary structure which may be composed of two or more elements joined together to form the golf club head 10. The face section 12, also called a striking plate, is an impact surface for contacting a golf ball (not shown). Structural material for the golf club head 10

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can be selected from metals and non-metals, with a face material exhibiting a maximum limit for face stiffness and natural frequency being a preferred embodiment.

The present invention is directed at a golf club head 10 having a striking plate 12 that makes use of materials to increase striking plate flexibility so that during impact less energy is lost, thereby increasing the energy transfer to the golf ball. This increased energy transfer to golf ball will result in greater impact efficiency. The striking plate 12 is generally composed of a single piece of metal or nonmetallic material and may have a plurality of score-lines 13 thereon. The striking plate 12 may be cast with a body 26, or it may be attached through bonding or welding to the body 26. See FIGS. 1 and 2.

For explanation purposes, the striking plate 12 is treated as an elliptical shaped cross section having a uniform thickness, denoted as "t" in FIG. 4, that is subjected to a distributed load over a small circular region at the center of the striking plate 12. See FIGS. 3 and 4. Those skilled in the pertinent art will recognize that striking plates having other shapes, nonuniform thickness distribution, and force locations are within the scope and spirit of the present invention. The overall cross-section width is given by (W=2a), the overall cross-section height (H=2b), and the striking plate aspect ratio is defined as ($\alpha=b/a$). The impact load, resulting from impact of the golf ball with the golf club head 10, is treated as force of magnitude (F), acting with a pressure (q) over a circular region of radius (r_0) in the center of the elliptical plate so that

$$F = \int_0^{2\pi} \int_0^{r_0} q r dr d\theta. \quad (I)$$

Like other striking plates of the prior art, the striking plate 12 of the present invention is positioned between the top section 16 and bottom section 18. During impact with the golf ball, the striking plate 12 will deflect depending upon the connection to the top section 16 and the bottom section 18, see FIGS. 5a-f. The two extreme limiting cases for all possible boundary attachment conditions are defined as "simply-supported" where the elliptical edge of the striking plate is constrained from translating but the edge is free to rotate, see FIGS. 5c and 5d, and "fixed" or "clamped" where the elliptical edge is fixed from both translating and rotating, see FIGS. 5e and 5f. The boundary attachment for the striking plate 12 to the body 26 of the club head 10 will fall between the two limiting cases since the top section 16 and bottom section 18 will provide some stiffening to the striking plate 12, but in general are very close to the simply supported condition. The calculated maximum stress in the striking plate as a result of the applied loading is

$$\sigma = \frac{3(1+\nu)RF^*}{2\pi t^2} \quad (II)$$

where (F*) is the maximum load that includes the effects of design safety factors and the score-line 13 stress concentration factors, (t) is the plate thickness, (ν) is the material Poisson ratio, and (R) depends upon the plate geometry (a,b), load radius, material Poisson ratio, and edge support conditions. For golf club heads, the top section 16 and bottom section 18 provide some stiffening to the striking plate 12 edge, (R) will fall between the simply-supported edge and the fixed support, but for this invention it is very close to the simply-support edge condition;

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$$R_{\text{simply-support}} = \ln\left(\frac{b}{r_o}\right) + \frac{\nu}{(1+\nu)}(6.57 - 2.57\alpha) \quad (\text{III.a,b})$$

$$R_{\text{fixed}} = \ln\left(\frac{2b}{r_o}\right) - .317\alpha - .376.$$

The minimum required thickness of the striking face based upon the applied loading is determined by setting the maximum stress to the allowable material yield stress (σ_{yield}) and solving;

$$t = \sqrt{\frac{3(1+\nu)RF^*}{2\pi\sigma_{\text{yield}}}}. \quad (\text{IV})$$

The minimum required striking plate thicknesses for two different materials (materials A and B) can be directly compared using Equation (IV), if one assumes that the impact forces, the plate geometry (W, H), and the edge boundary constraints are nearly the same. Writing the ratio of the minimum required thicknesses for two different materials is

$$\frac{t_A}{t_B} = \sqrt{\frac{(\sigma_{\text{yield-B}})(1+\nu_A)}{(\sigma_{\text{yield-A}})(1+\nu_B)}}. \quad (\text{V})$$

where (t_A) and (t_B) are the minimum required thicknesses for plates composed of materials A and B, respectively, and ($\sigma_{\text{yield-A}}$, ν_A) and ($\sigma_{\text{yield-B}}$, ν_B) are the material properties of A and B, respectively. A weight ratio comparison of two minimum thickness striking plates is equal to

$$\frac{W_A}{W_B} = \frac{\rho_A t_A \pi a b}{\rho_B t_B \pi a b} = \frac{\rho_A}{\rho_B} \sqrt{\frac{(\sigma_{\text{yield-B}})(1+\nu_A)}{(\sigma_{\text{yield-A}})(1+\nu_B)}}. \quad (\text{VI})$$

where (σ_A) and (σ_B) are the densities of material A and B, respectively, and these plates have identical geometry (W, H), boundary constraints, and are designed to withstand the same load (F^*).

Static Flexibility

The calculated striking plate static flexibility (S), which is the inverse of the plate stiffness, is defined as the calculated center displacement of the striking plate 12 divided by the plate force (F^*) and is equal to:

$$S = \frac{b^2}{E\pi} P, \quad (\text{VII})$$

where (b) is half the height of the striking plate 12, (E) is Young's modulus and (P) depends upon the geometry and the support conditions of the elliptical plate. For golf heads, (P) will fall between the simply-supported and fixed edge conditions, but for this invention it falls very close to the simply-supported edge condition;

Thus, increased striking plate flexibility can be accomplished by increasing the striking plate height (b), decreasing the Young's modulus (E), also described as material stiffness, or by reducing to plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV) into (VII), results in the static flexibility having a minimum allowable plate thickness;

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$$S = \left[\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{3/2} \right] \left[P b^2 \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right], \quad (\text{IX})$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (P, R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are the same for two different designs (second bracketed term of Equation IX), then to maximize the static flexibility, one needs to select a material having the largest ratio of:

$$\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{3/2}. \quad (\text{X})$$

The static flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (IX) as a ratio

$$\frac{S_A}{S_B} = \left(\frac{E_B}{E_A} \left(\frac{\sigma_{\text{yield-A}}}{\sigma_{\text{yield-B}}} \right)^2 \left(\frac{1+\nu_B}{1+\nu_A} \right)^2 \right)^{3/2}, \quad (\text{XI})$$

where (S_A) and (S_B) are the static flexibilities of a plate having a minimum plate thickness for materials A and B, respectively and (E_A) and (E_B) are the material stiffnesses for materials A and B, respectively.

Bending Natural Frequency

The calculated bending natural frequency (ω), or referred to simply as natural frequency, having units of cycles/second (Hz), for the elliptical striking plate is given by;

$$\omega(\text{Hz}) = \frac{\lambda t}{b^2} \sqrt{\frac{Eg}{\rho(1-\nu^2)}} \quad (\text{XII})$$

where (ν) is the material Poisson ratio, (b) is half the height of the striking plate 12, (ρ) is the material weight density, (g) is the gravitational constant (32.2 ft/sec²), and (λ) depends upon the geometry and the support conditions of the elliptical plate, as well as the desired vibration mode. For golf club heads, (λ) will fall between the two limiting edge support values, simply-support and fixed, but for this invention it is very close to the simply-support condition;

$$\lambda_{\text{simply-support}} = 0.124\sqrt{1+0.21\alpha+2.37\alpha^2-3.03\alpha^3+2.7\alpha^4}$$

$$\lambda_{\text{fixed}} = .2877\sqrt{1+2/3\alpha^2+\alpha^4}. \quad (\text{XIII.a,b})$$

The bending natural frequency can be minimized by increasing the striking plate 12 height (2b) or aspect ratio (α), increasing the material density (ρ), decreasing the material stiffness (E), or decreasing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV) into (XII), results in the natural frequency having a minimum allowable plate thickness;

$$\omega = \left[\sqrt{\frac{E}{\sigma_{\text{yield}} \rho (1-\nu)}} \right] \left[\frac{\lambda}{b^2} \sqrt{\frac{3gRF^*}{2\pi}} \right] \quad (\text{XIV})$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment con-

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straints (R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are the fixed (second bracketed term of Equation XIV), then to minimize the natural frequency, one needs to select a material having the smallest of:

$$\frac{E}{\sigma_{yield}\rho(1-\nu)} \quad (XV)$$

The natural frequency of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XIV) as a ratio

$$\frac{\omega_A}{\omega_B} = \sqrt{\left(\frac{E_A}{E_B}\right)\left(\frac{\sigma_{yield-B}}{\sigma_{yield-A}}\right)\left(\frac{\rho_B}{\rho_A}\right)\left(\frac{1-\nu_B}{1-\nu_A}\right)}, \quad (XVI)$$

where (ω_A) and (ω_B) are the natural frequencies of a striking plate having a minimum plate thickness for materials A and B.

A golf club head has a large number of natural frequencies, where some involve the vibratory motion that characterize the striking plate, others involve motion that characterize the top plate or bottom plate, and still others involve the combined motion of the striking plate and other parts of the club head. The natural frequencies that are of concern in the present invention involve the full or partial vibratory motion of the striking plate. Thus, to experimentally measure these frequencies, one needs to excite the striking plate as well as record its response. A noncontacting excitation and response system is preferred to insure that added mass or stiffness effects do not artificially alter the results. In our experimental studies, the striking plate was excited using either an impact hammer (PCB Inc. of Buffalo, N.Y., model 068, series 291; or Kistler Instrument Corp. of Amherst, N.Y., model 9722A500) or an acoustical funnel-cone speaker, where the speaker is driven with broad-band "white" random noise between 1000–10,000 Hz. The velocity time history (response) is measured using a laser velocimeter (Polytec PI GmbH of Waldbronn, Germany, model OFV-303 or PSV-300; or Ometron Inc. of London, England, model VPI-4000). The recorded excitation and response time histories are processed using a two-channel spectrum analyzer (Hewlett Packard of Palo Alto, Calif.) to determine the frequency content of the response signal divided by the excitation signal. The spectrum analyzer has input/output windowing features and anti-aliasing filters to eliminate processing errors. The test is repeated a minimum of 10 times and the data is averaged to minimize the effects of uncorrelated noise. Thus the coherence was found to be greater than 0.98 at all measured natural frequencies. The tests are repeated using numerous excitation and response locations on the striking plate to insure that the lowest striking plate dominated natural frequencies are recorded.

Dynamic Flexibility

The dynamic flexibility (D) for the striking plate is given by

$$D = \frac{1}{m_e(2\pi\omega)^2}, \quad (XVII)$$

where, (ω) is the striking plate natural frequency, and (m_e) is the effective face mass that contributes to the dynamic response during impact:

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$$m_e = \beta \frac{\rho}{g} \pi t a b = \beta \frac{\rho}{g} \pi t \frac{b^2}{\alpha}, \quad (XVIII)$$

Here (β) is defined between (0) and (1), where (0) is associated with no face mass contributing to the dynamic response and (1) having all of the face mass contributing to the response. For golf clubs, ($0.15 < \beta < 0.35$). Writing the dynamic flexibility by substituting Equations (XIV) and (XVIII) into (XVII):

$$D = \frac{b^2}{E t^3} \left(\frac{\alpha(1-\nu^2)}{4\beta\pi^3\lambda^2} \right), \quad (XIX)$$

The striking plate dynamic flexibility can be increased by enlarging the plate depth (b) or aspect ratio (α), decreasing the material stiffness (E), or decreasing the plate thickness (t). Clearly the greatest increase in (D) can be found by changing the thickness (t), followed by changing the face height (2b). But, the plate thickness can only be reduced up to the allowable value of Equation (IV). Thus, the maximum dynamic flexibility (D) for a given plate geometry and applied load is calculated by substituting the minimum allowable thickness Equation (IV) into (XIX);

$$D = \left[\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \right] \left[\left(\frac{\alpha b^2}{4\beta\pi^3\lambda^2} \right) \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right] \quad (XX)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (λ , R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are constant (second bracketed term of Equation XX), then to maximize the dynamic flexibility (D), one needs to select a material having the largest ratio of:

$$\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \quad (XXI)$$

The dynamic flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XX) as a ratio

$$\frac{D_A}{D_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{1-\nu_A^2}{1-\nu_B^2} \right) \left(\frac{\sigma_{yield-A}}{\sigma_{yield-B}} \right)^{3/2} \left(\frac{1+\nu_B}{1+\nu_A} \right)^{3/2}, \quad (XXII)$$

where (D_A) and (D_B) are the maximum dynamic flexibilities of a plate having a minimum plate thickness for materials A and B, respectively.

For wood-type golf clubs the following geometry and force properties are typical (a=1.4–1.65 inch, b=0.7–1.0 inch, t=0.14–0.25 inch, F*=2000–15,000 lbs). In Table 1, current metal golf club head material properties are given along with five different golf club head property ratios. These five different ratios include: minimum required striking plate thickness (Eq. V), resulting striking plate weight (Eq. VI), static flexibility (Eq. XI), bending natural frequency (Eq. XVI), and dynamic flexibility (Eq. XXII), where the baseline (B) material is taken as (17-4) Stainless Steel. These ratios provide a comparison of striking plates that have identical elliptical geometry, edge attachment, and load capacity, but are composed of different materials and

thus will have different minimum striking plate thicknesses. A normalized comparison of the static flexibility and dynamic flexibility to face weight is presented in FIG. 6, where all results are normalized to an equivalent (17-4) Stainless Steel striking plate. In FIG. 6, it is clear that the amorphous alloy striking plate and maraging striking plate

phous alloy and maraging steel have bending natural frequencies which are 41% and 27% lower, respectively, than the 17-4 Stainless Steel striking plate, whereas the titanium alloy striking plate is nearly the same as the stainless steel, while the aluminum alloy striking plate is 50% greater as a result of an increased thickness and low density.

TABLE 1

Typical Material Properties used in Golf Club Faces and Comparison Ratios									
Material (i)	E 10 ⁶ lb/in ²	ν	σ_{yield} 10 ³ lb/in ²	ρ lb/in ³	t_i/t_{steel}	W_i/W_{steel}	S_i/S_{steel}	ω_i/ω_{steel}	D_i/D_{steel}
Stainless Steel (17-4)	29.0	.27	150	.276	1.00	1.00	1.00	1.00	1.00
Aluminum 7075-T6)	10.4	.33	73	.101	1.47	0.54	0.88	1.48	0.85
Titanium Ti6-4)	16.0	.31	138	.160	1.06	0.61	1.53	1.05	1.49
Maraging 280 Steel	26.5	.31	262	.285	0.77	0.79	2.41	0.73	2.35
Amorphous Alloy	13.3	.30	260	.220	0.77	0.61	4.80	0.59	4.72

offer (4.8) and (2.5) times more flexibility and lower face weight than stainless steel as a result of their high strength, while the titanium alloy striking plate offers 50% more flexibility and lower face weight as a result of significantly lower modulus, but that the aluminum alloy striking plate results in lower flexibility as a result of its lower strength. These increases in flexibility lead to reduced impact energy losses, which in turn lead to greater golf ball flight velocities. In FIG. 7, a comparison of normalized face natural frequency versus static flexibility is presented, where a correlation exists between measured natural frequency and static flexibility, and thus natural frequency can be used as a simple nondestructive measurement technique for assessing the magnitude of the static and dynamic flexibility. It is observed that the amorphous alloy and maraging steel striking plates have a lower natural frequency and greater flexibility than other materials in FIG. 7 because of their high strength and density. The titanium alloy striking plate and aluminum alloy striking plate have natural frequencies higher than all the other materials in FIG. 7 because of their low density.

A detailed inspection of Table 1 reveals that striking plates composed of Maraging 280 steel or the amorphous alloy are 23% thinner than the 17-4 Stainless Steel striking plate, which is a direct result of higher strength of these materials. In a preferred embodiment the striking plate of stainless steel has a maximum thickness of less than 0.130 inches, and more preferably between 0.130 and 0.070 inches, while both the maraging steel and amorphous alloy have a striking plate thickness of less than 0.100 inches, and more preferably between 0.100 and 0.070 inches. The Aluminum 7075-T6 striking plate is thickest because of its low strength, but it is the lightest as a result of its low density. In a preferred embodiment the striking plate of aluminum alloy has a maximum thickness of less than 0.200 inches, and more preferably between 0.200 and 0.070 inches. The striking plates composed of an amorphous alloy, Maraging 280 steel, and the 6-4 Titanium all have static and dynamic flexibilities much greater than the 17-4 Stainless Steel striking plate (480%, 240% and 150%), while the aluminum alloy striking plate has a 12% lower flexibility as a result of its large thickness. Finally, the striking plates composed of amor-

As a second example, consider a very large oversized driver head similar to a Callaway Golf® Biggest Big Bertha driver that is fabricated with different material striking plates. The geometry values are defined as (a=1.65 inch, b=0.875 inch, $\alpha=0.530$). In order to produce striking plate flexibility levels greater than found in any current club-head: (1) the striking plate has no scorelines, thus ($F^*=2500$ lbs) with a radius ($r_o=0.50$ inch), and (2) the edge attachment condition is nearly simply-supported so that ($P=0.664$, $\lambda=0.1538$). Constructing the striking plate out of Titanium (Ti 6-4), leads to ($R=1.792$) and a minimum required face thickness of ($t=0.143$ inch). Including score-line stress concentration factors will simply increase (F^*), thus increasing the required face thickness (t) and bending natural frequency, and decreasing the flexibility. The calculated weight is ($W=0.103$ lb), the static flexibility is ($S=1.10 \times 10^{-5}$ in/lb), the natural frequency ($\omega=5920$ Hz), and the dynamic flexibility ($D=1.08 \times 10^{-5}$ in/lb), where it was assumed ($\beta=0.25$). The calculated head natural frequency of 5920 Hz is within 2% of the experimentally measured value of 6040 Hz on an actual experimental hybrid golf club head. The maximum displacement of the striking plate is found by multiplying the static flexibility and the effective force (F^*), thus ($\beta=0.0275$ inch). Hybrid golf club heads having different material striking face plates are presented in Table 2, where the striking plates have minimum allowable face thicknesses. In FIGS. 8 and 9, the variation of the static flexibility and natural frequency with striking plate thickness is presented for the five different metals, where the symbol (o) is used to represent the minimum allowable thickness for a assumed applied load ($F^*=2500$ lbs). Clearly, if the applied load were increased then the minimum allowable thicknesses would increase, where the symbols would just move to the right along the appropriate curve. Thus lowering the flexibility and increasing the natural frequency. Moreover, if a higher strength version of an alloy were used, then the symbol would follow the curve to the left and thus increase the flexibility and lower natural frequency. It is observed that the greatest flexibility occurs for maraging steel and the amorphous alloy, which has the thinnest striking plates and lowest natural frequencies.

It is known through experimental testing, that currently available driver golf club heads have striking-face natural frequencies greater than 4500 Hz. Moreover, the only com-

mercially available golf club head with an amorphous alloy striking plate (commercial name: Liquid Metal[®]) has a fundamental striking plate natural frequency of 5850 Hz. Thus, the striking plates on these club heads are not optimized for maximum flexibility. They do not have a minimum thickness striking plate, a large aspect ratio, or an edge support that simulates the simply supported constraint. From Equation XVII, the dynamic flexibility is inversely proportional to the square of the natural frequency, thus these heads have a flexibility that is much lower and a face thickness that is much greater than the optimized minimum values presented in the previous example (i.e. their values on FIGS. 8 and 9 would be to the far right of the minimum allowable thickness). In a preferred embodiment of the present invention, the material of striking plate 12 has a natural frequency of less than 4500 Hz, in a more preferred embodiment the striking plate 12 natural frequency is between 4500 Hz and 2800 Hz. For the aluminum alloy striking plate 12, the natural frequency is below 8500 Hz, and in a more preferred embodiment the natural frequency is between 8500 Hz and 2800 Hz. For the titanium alloy striking plate 12, the natural frequency is below 5900 Hz, and in a more preferred embodiment the natural frequency is between 5900 Hz and 2800 Hz. For the stainless steel striking plate 12, the natural frequency is below 5400 Hz, and in a more preferred embodiment the natural frequency is between 5400 Hz and 2800 Hz. For the maraging steel striking plate 12, the natural frequency is below 6000 Hz, and in a more preferred embodiment the natural frequency is between 6000 Hz and 2800 Hz. For the amorphous alloy striking plate 12, the natural frequency is below 5500 Hz, and in a more preferred embodiment the natural frequency is between 5500 Hz and 2800 Hz.

cubic centimeters to 450 cubic centimeters, even more preferably 350 cubic centimeters to 400 cubic centimeters, and is most preferably 385 cubic centimeters for a body composed of titanium, or titanium alloy. However, a body composed of stainless steel may have a volume range of 200 cubic centimeters to 325 cubic centimeters, and a body composed of a composite material (such as plies of continuous carbon fiber pre-preg material) may have a volume of 325 cubic centimeters to 600 cubic centimeters. The body preferably weighs no more than 215 grams, and most preferably weighs between 180 and 205 grams. The body has a hollow interior.

From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

- I claim as my invention:
1. A wood-type golf club head comprising:
a body having a top region, a bottom region, a rear region and an open front;
a striking plate disposed in the open front of the body, the striking plate having a plurality of scorelines thereon,

TABLE 2

Calculated Striking Plate Properties for a Hybrid Oversized Driver Golf Club Head without scorelines (a = 1.65", b = .875", α = .530, F* = 2500 lb, r ₀ = 0.5", P = 0.664, λ = .154, β = 0.25).											
Material (i)	E 10 ⁶ lb/in ²	ν	σ _{yield} 10 ³ lb/in ²	ρ lb/in ³	R	T Inch	W lb	S 10 ⁻⁵ in/lb	Δ inch	ω (Hz)	D 10 ⁻⁵ in/lb
Stainless Steel (17-4)	29.0	.27	150	.276	1.67	.130	.162	.803	.020	5458	.809
Aluminum (7075-T6)	10.4	.33	73	.101	1.85	.200	.092	.605	.015	8520	.586
Titanium Ti-6	16.0	.31	138	.160	1.79	.142	.103	1.10	.027	5920	1.08
Maraging Steel	26.5	.31	262	.285	1.79	.103	.134	1.74	.043	4143	1.71
Amorphous Alloy	13.3	.30	260	.220	1.76	.102	.102	3.55	.089	3301	3.51

Although the above description is for wood-type golf club heads having an elliptical face section, the present invention is not limited to such an embodiment. Also included within the bounds of the present invention are iron type golf club heads and golf club heads with α values approaching 1.0. The golf club head 10 is a fairway wood or a driver. The golf club head 10 has a body 26, excluding the striking plate 12, that is preferably composed of a metal material such as titanium, titanium alloy, stainless steel, or the like, and is most preferably composed of a forged titanium material. However, the body 26, or a portion of the body 26, may be composed of a graphite composite material or the like. The body 26 preferably has a large volume, most preferably greater than 300 cubic centimeters, more preferably 300

- the striking plate composed of a titanium alloy material and having a thickness less than 0.200 inch and greater than 0.070 inch, the striking plate having a natural frequency of less than 4500 Hz and greater than 2800 Hz.
2. The wood-type golf club head according to claim 1 wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.
 3. A wood-type golf club head comprising:
a body having a top region, a bottom region, a rear region and an open front;
a striking plate disposed in the open front of the body, the striking plate composed of a titanium alloy material and

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having a thickness less than 0.140 inch, the striking plate having a plurality of scorelines thereon, the striking plate having a natural frequency of less than 8500 Hz and greater than 2800 Hz.

4. The wood-type golf club head according to claim 1 5
wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

5. A wood-type golf club head comprising:

a body having a striking plate, the striking plate composed 10
of a titanium alloy material and having a thickness less than 0.200 inch and greater than 0.070 inch, the striking plate having a plurality of scorelines thereon, the striking plate having a natural frequency of less than 4000 Hz and greater than 2800 Hz.

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6. A wood-type golf club head comprising:

a body having a top region, a bottom region, a rear region and an open front, the body composed of a non-metallic material;

a striking plate disposed in the open front of the body, the striking plate composed of a titanium alloy material and having a thickness less than 0.140 inch, the striking plate having a plurality of scorelines thereon, the striking plate having a natural frequency of less than 8500 Hz and greater than 2800 Hz.

7. The wood-type golf club head according to claim 1
wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

* * * * *

Exhibit E

(12) **United States Patent**
Kosmatka

(10) **Patent No.:** **US 6,949,032 B2**
(45) **Date of Patent:** ***Sep. 27, 2005**

(54) **GOLF CLUB HEAD HAVING A STRIKING
FACE WITH IMPROVED IMPACT
EFFICIENCY**

(58) **Field of Search** 473/324, 332,
473/349, 350, 329, 342, 345, 346, 290,
291

(75) **Inventor:** **John B. Kosmatka**, Encinitas, CA (US)

(56) **References Cited**

(73) **Assignee:** **Callaway Golf Company**, Carlsbad,
CA (US)

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(*) **Notice:** Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 84 days.

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This patent is subject to a terminal dis-
claimer.

* cited by examiner

(21) **Appl. No.:** **10/767,116**

(22) **Filed:** **Jan. 28, 2004**

Primary Examiner—Raleigh W. Chiu

(65) **Prior Publication Data**

(74) *Attorney, Agent, or Firm*—Michael A. Catania; Elaine
H. Lo

US 2004/0185959 A1 Sep. 23, 2004

(57) **ABSTRACT**

Related U.S. Application Data

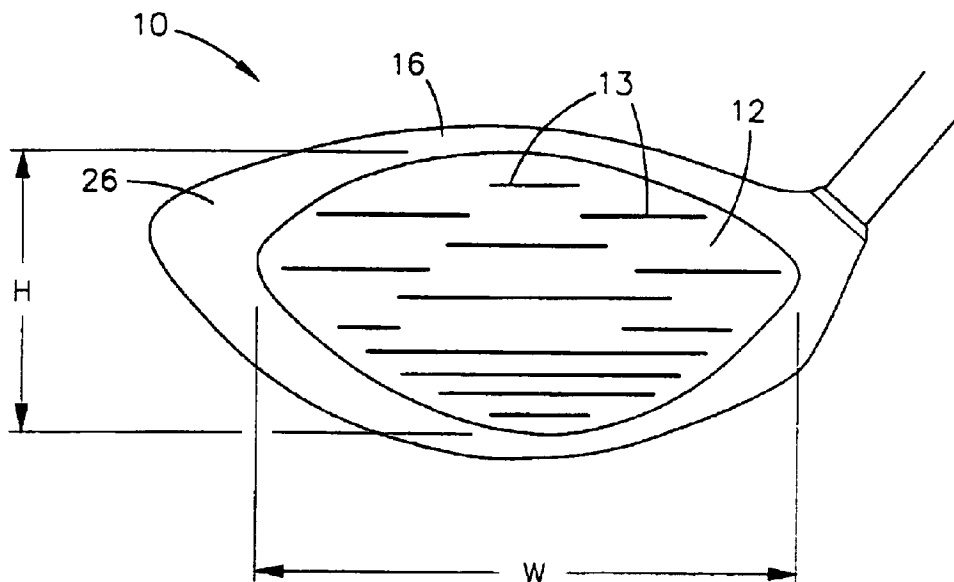
A compliant golf club head permits a more efficient impact
between a golf ball and the golf club head. Material and
geometry constraints of a striking plate of the golf club head
can reduce energy losses caused by large strain and strain
rate values of the golf ball, these constraints on the striking
plate yield a measure of the impact efficiency of the golf club
head. Designating a required natural frequency range of the
striking plate provides improved impact efficiency between
the golf ball the golf club head.

(63) Continuation of application No. 10/250,194, filed on Jun. 11,
2003, now Pat. No. 6,685,576, which is a continuation of
application No. 10/065,690, filed on Nov. 8, 2002, now Pat.
No. 6,669,579, which is a continuation of application No.
09/683,799, filed on Feb. 15, 2002, now Pat. No. 6,478,692,
which is a continuation-in-part of application No. 09/525,
216, filed on Mar. 14, 2000, now Pat. No. 6,348,015.

(51) **Int. Cl.**⁷ **A63B 53/04**

(52) **U.S. Cl.** **473/342; 473/329; 473/345;**
473/349; 473/350

6 Claims, 7 Drawing Sheets



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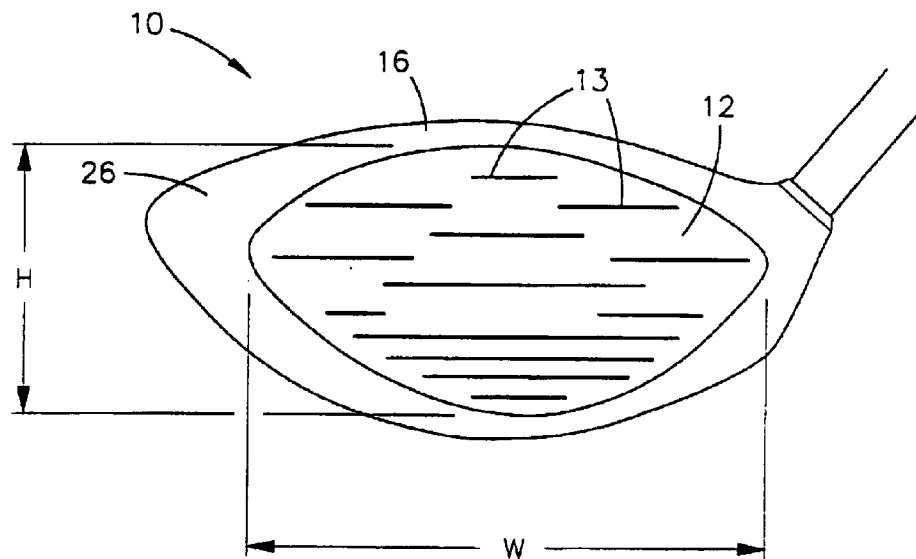
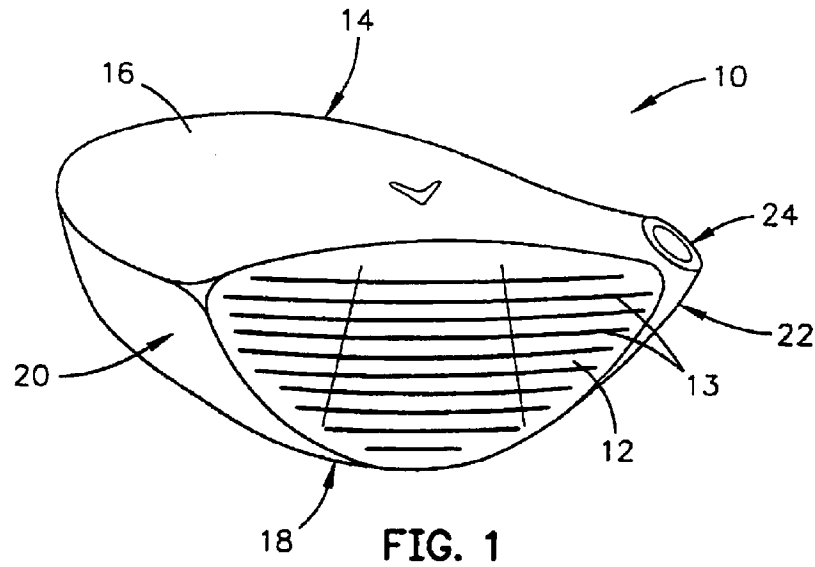


FIG. 2

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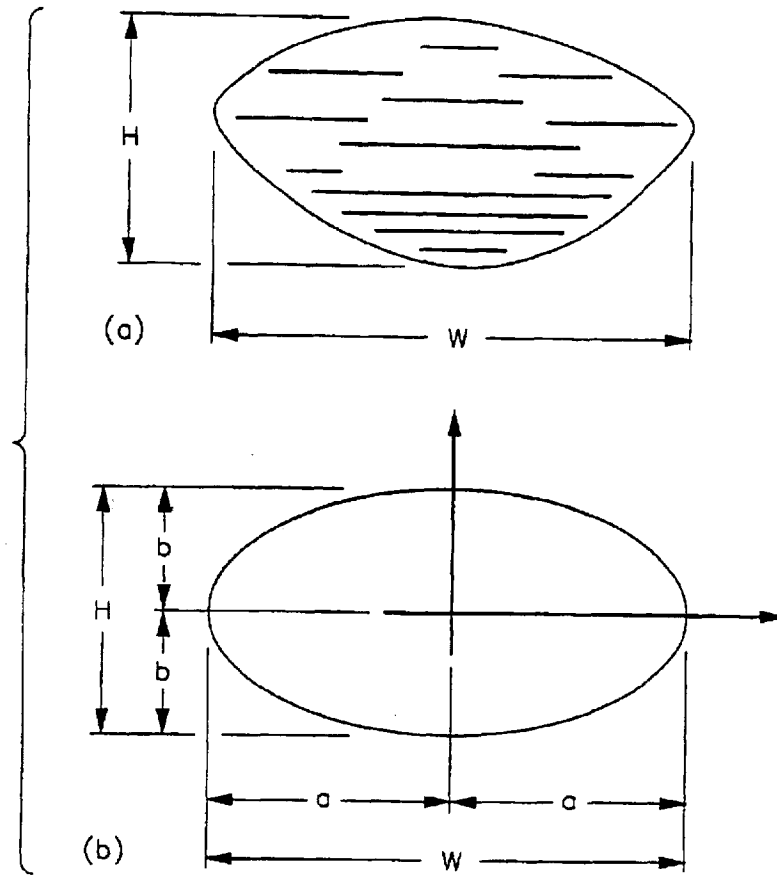


FIG. 3

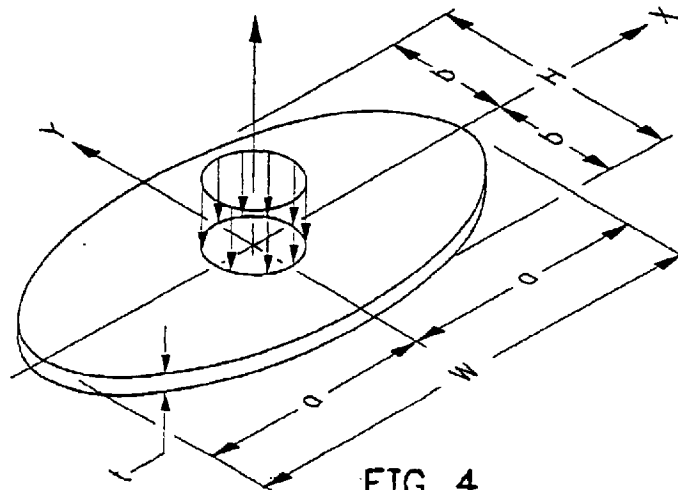


FIG. 4

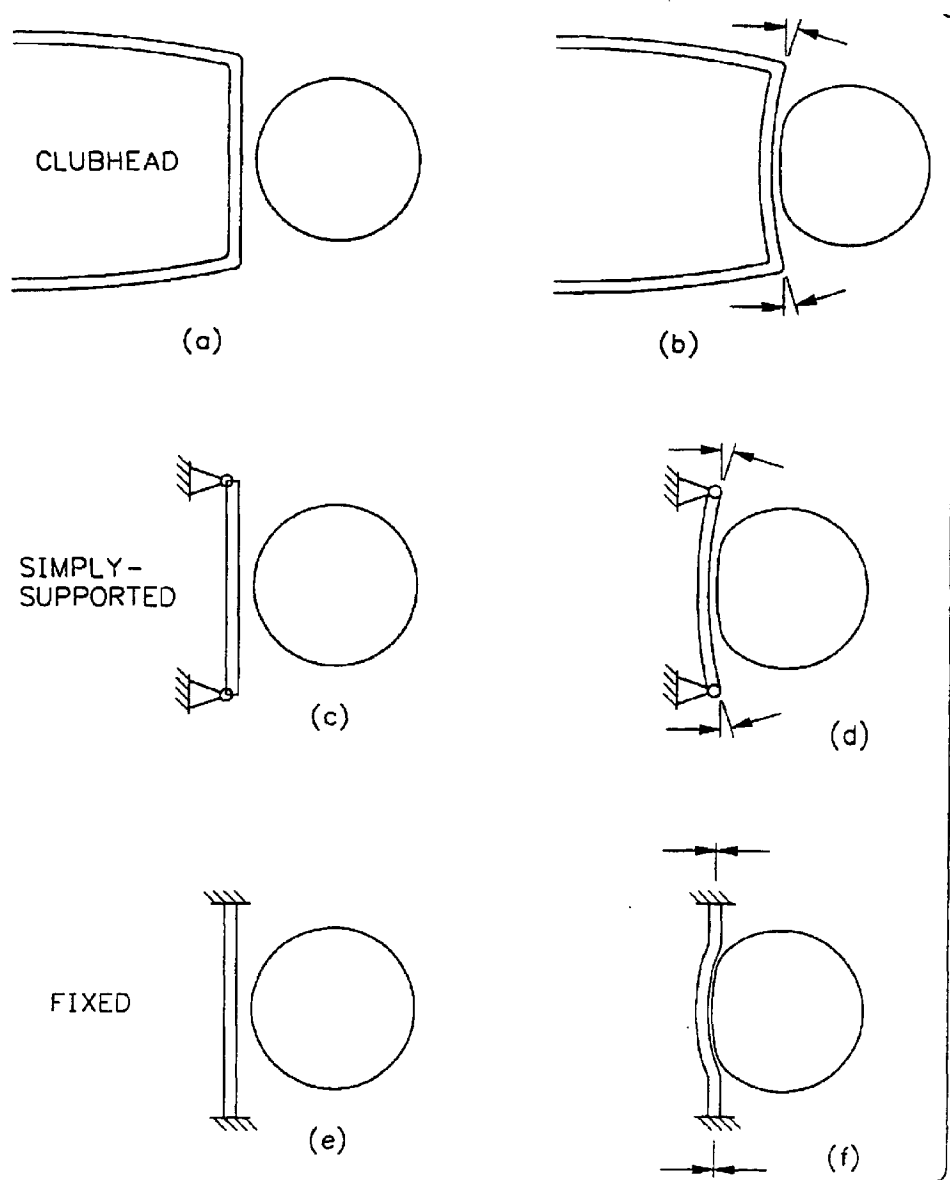


FIG. 5

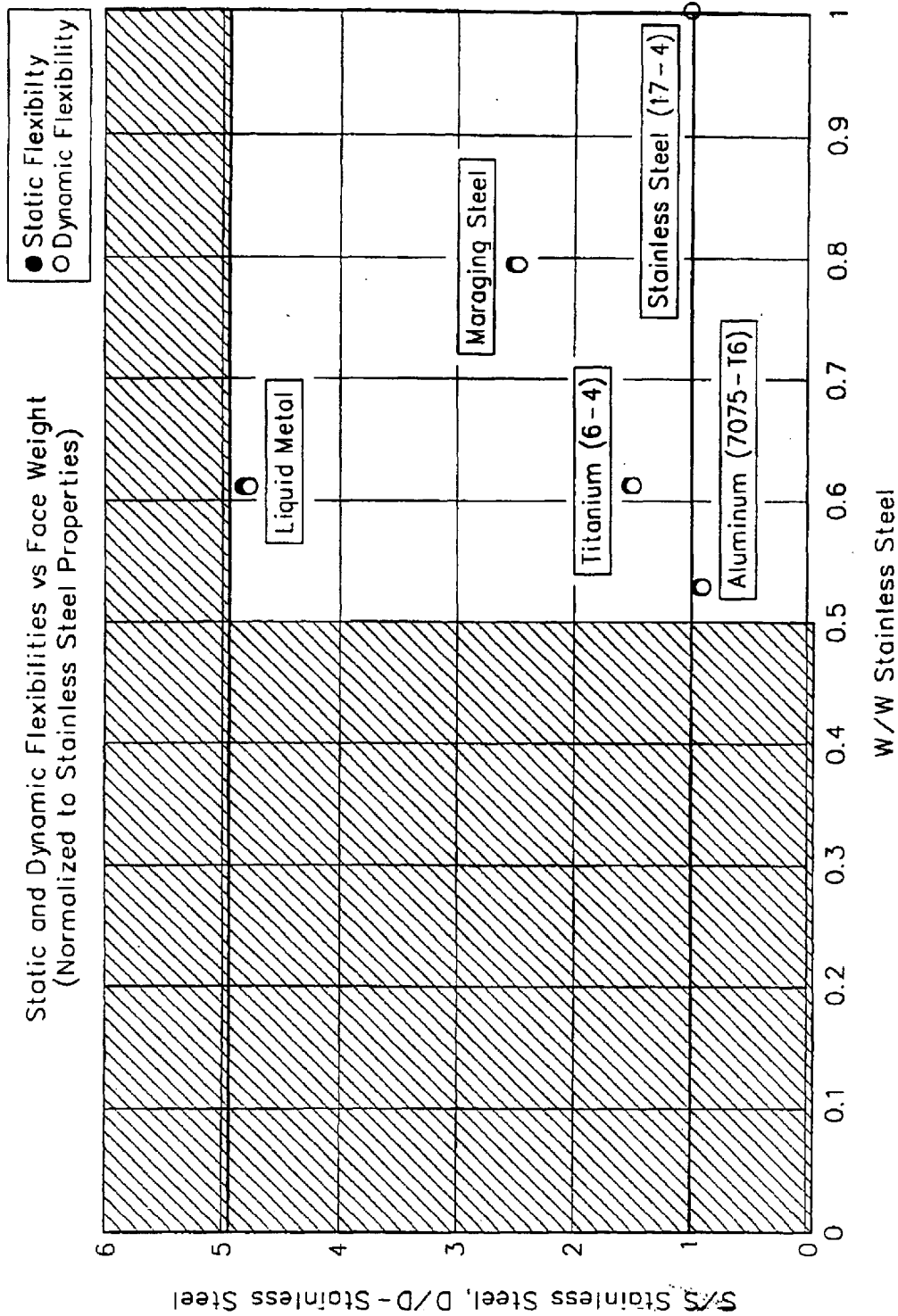


FIG. 6

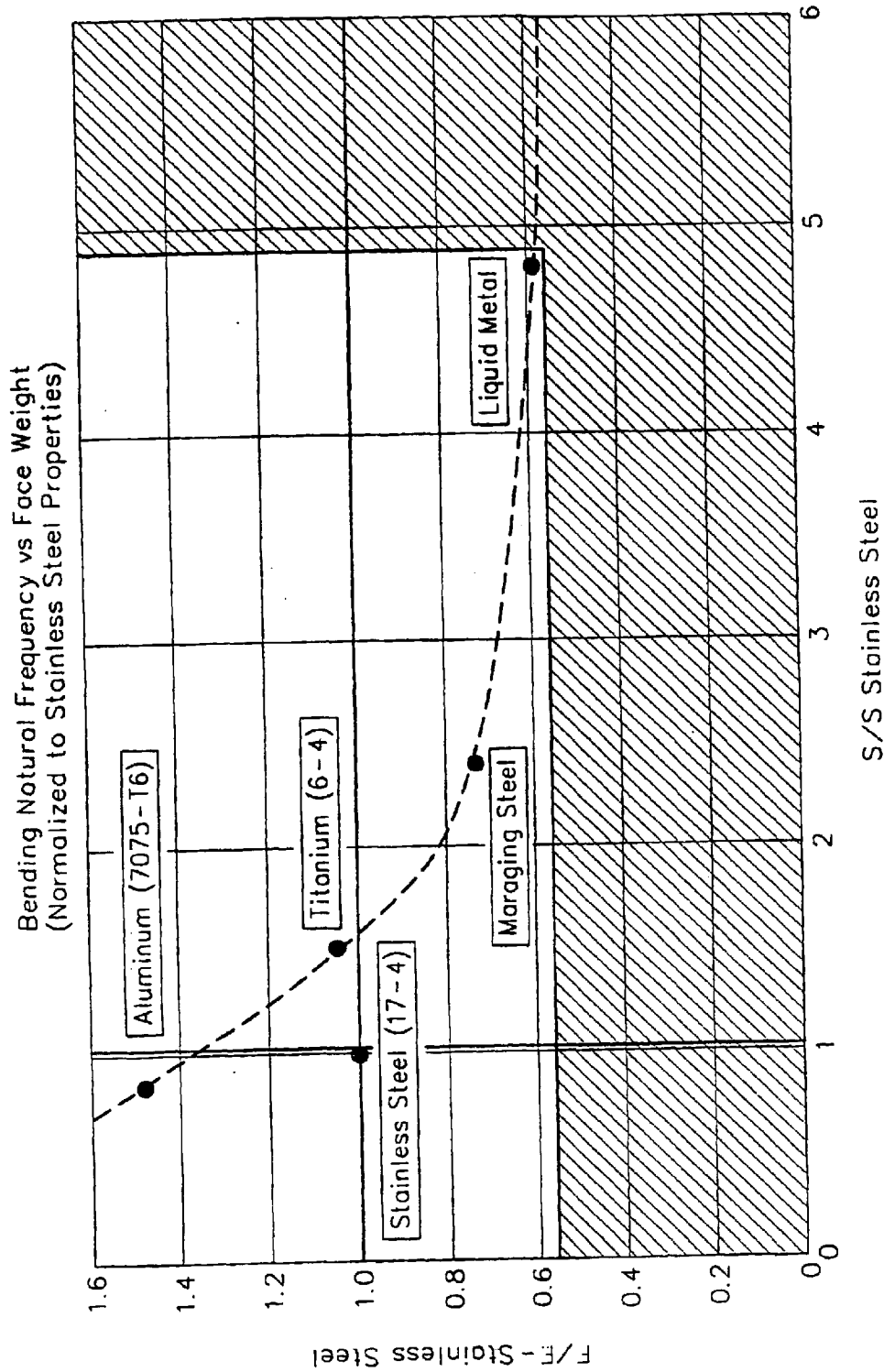


FIG. 7

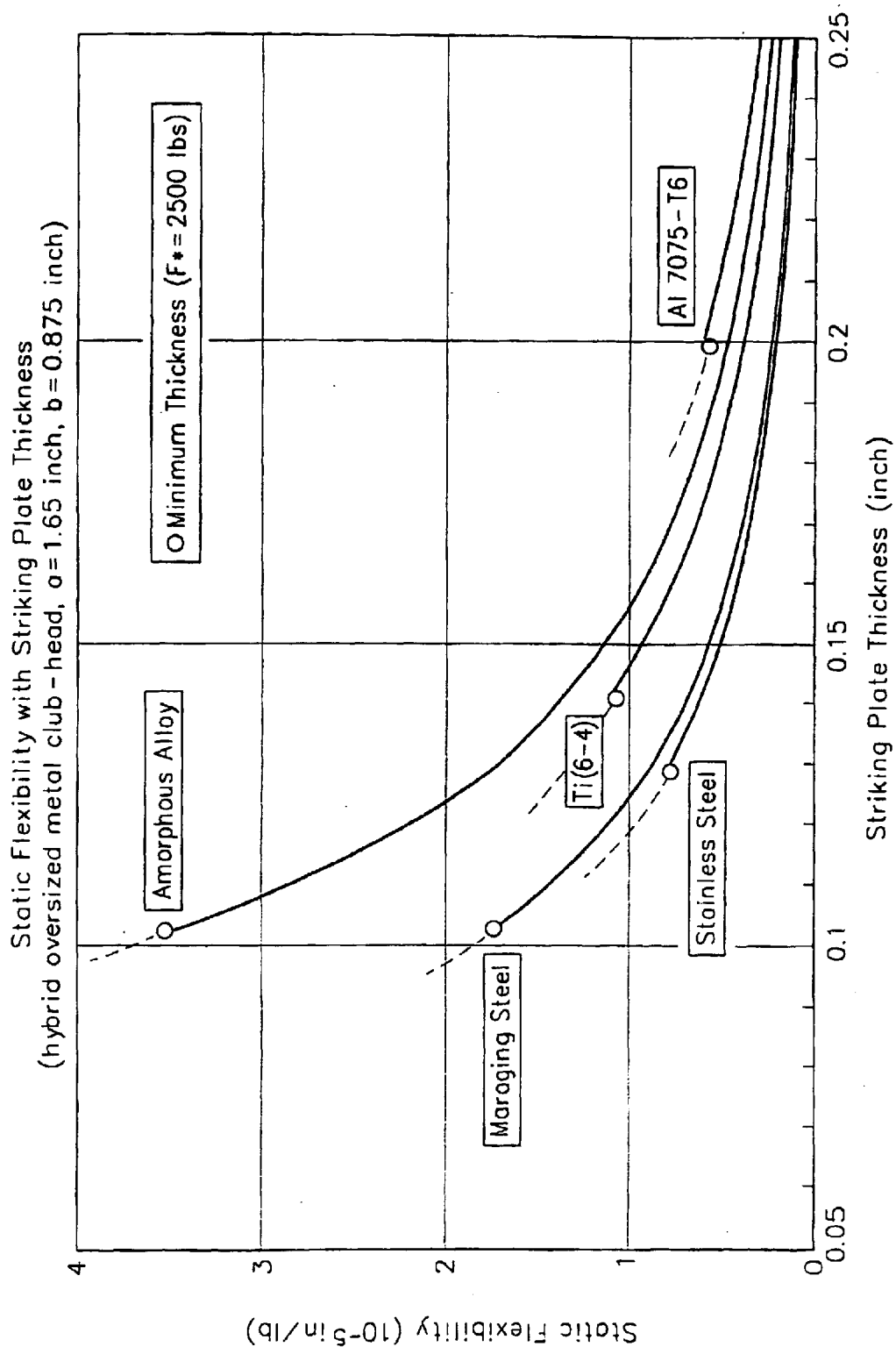


FIG. 8

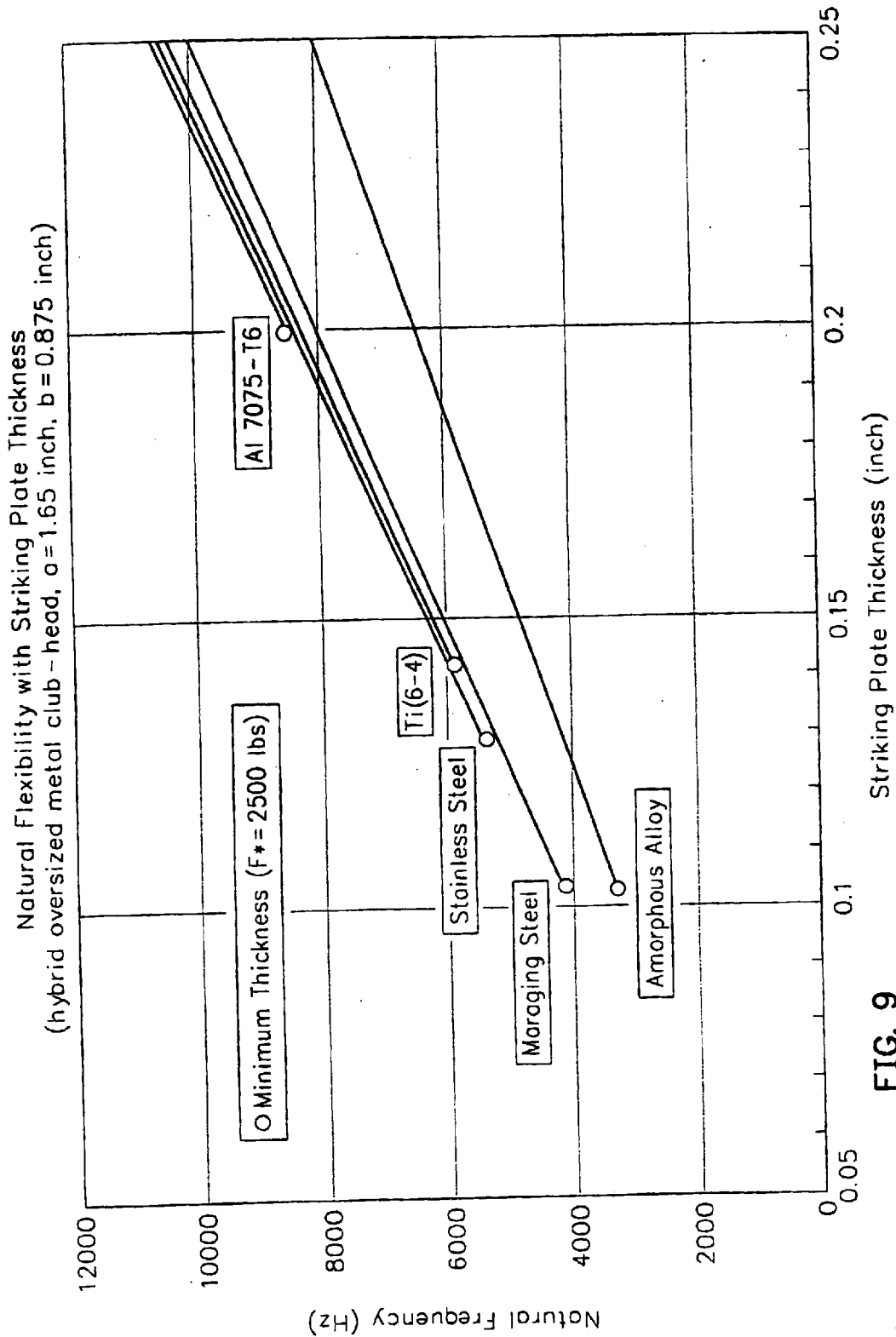


FIG. 9

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GOLF CLUB HEAD HAVING A STRIKING FACE WITH IMPROVED IMPACT EFFICIENCY

CROSS REFERENCES TO RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 10/250,194, filed on Jun. 11, 2003, now U.S. Pat. No. 6,685,576, which is a continuation application of U.S. patent application Ser. No. 10/065,690, filed on Nov. 8, 2002, now U.S. Pat. No. 6,669,579, which is a continuation application of U.S. patent application Ser. No. 09/683,799, filed on Feb. 15, 2002, now U.S. Pat. No. 6,478,692, which is a continuation-in-part application of U.S. patent application Ser. No. 09/525,216 filed on Mar. 14, 2000, now U.S. Pat. No. 6,348,015,

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a golf club head. More specifically, the present invention relates to a face section of a golf club head to reduce energy losses when impacting a golf ball.

2. Description of the Related Art

Technical innovation in the material, construction and performance of golf clubs has resulted in a variety of new products. The advent of metals as a structural material has largely replaced natural wood for wood-type golf club heads, and is but one example of this technical innovation resulting in a major change in the golf industry. In conjunction with such major changes are smaller scale refinements to likewise achieve dramatic results in golf club performance. For example, the metals comprising the structural elements of a golf club head have distinct requirements according to location in the golf club head. A sole or bottom section of the golf club head should be capable of withstanding high frictional forces for contacting the ground. A crown or top section should be lightweight to maintain a low center of gravity. A front or face of the golf club head should exhibit high strength and durability to withstand repeated impact with a golf ball. While various metals and composites are known for use in the face, several problems arise from the use of existing materials.

Existing golf club face materials such as stainless steel exhibit desired high strength and durability but incur large energy losses during impact with the golf ball as a result of large ball deformations. An improvement in impact energy conservation, in conjunction with proper golf ball launch parameters, is a design goal for golf club manufacturers. The problem still exists of identifying a combination of material properties exhibiting improvements in conservation of impact energy during impact with the golf ball.

BRIEF SUMMARY OF THE INVENTION

When a golf club head strikes a golf ball, large impact forces are produced that load a face section, also called a striking plate, of the golf club head. Most of the energy is transferred from the golf club head to the golf ball; however, some energy is lost as a result of the impact. The present invention comprises a golf club striking plate material and geometry having a unique combination of material properties for improved energy efficiency during impact with the golf ball.

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The golf ball is typically a core-shell arrangement composed of polymer cover materials, such as ionomers, surrounding a rubber-like core. The golf ball materials have stiffness properties defined as the storage and loss moduli for compression (E'_{ball} , E''_{ball}) and storage and loss moduli for shear (G'_{ball} , G''_{ball}) that are strain (or load), strain rate (or time rate of loading), input frequency, and temperature dependent. The compression loss factor (η_E) and shear loss factor (η_G) (damping or energy loss mechanisms), which are defined as the ratio of loss modulus to the storage modulus, are also strain, strain rate, input frequency, and temperature dependent. The golf ball loss factors, or damping level, is on the order of 10–100 times larger than the damping level of a metallic golf club striking plate. Thus, during impact most of the energy is lost as a result of the large deformations, typically 0.05 to 0.50 inches, and deformation rates of the golf ball as opposed to the small deformations of the metallic striking plate of the golf club head, typically 0.025 to 0.050 inches.

By allowing the golf club head to flex and “cradle” the golf ball during impact, the contact region as well as contact time between the golf ball and the striking plate of the golf club head are increased, thus reducing the magnitude of the internal golf ball stresses as well as the rate of the stress build-up. This results in smaller golf ball deformations and lowers deformation rates, both of which produce much lower energy losses in the golf ball during impact. The static flexibility is inversely proportional to the striking plate stiffness, while the dynamic flexibility is inversely proportional to square of the striking plate bending natural frequency. In other words, a decrease in plate stiffness will cause the static flexibility to increase, while doubling the plate bending natural frequency will reduce dynamic flexibility to a level $\frac{1}{4}$ of the original striking plate. Increasing the static or dynamic flexibility can be accomplished via several different configurations for the golf club head: altering geometry of the face section; altering attachment of the striking plate to the club-head body; reducing the thickness of the striking plate; or through the innovative use of new structural materials having reduced material stiffness and/or increased material density. Material strength of the striking plate of the golf club head in conjunction with impact load from contact with the golf ball determines the minimum required thickness for the face section. The greater the available material strength, the thinner the striking plate can be, and thus greater the flexibility. So the material properties that control static and dynamic flexibility are decreased compression stiffness, increased density, and increased strength. The present invention specifies which face materials and static/dynamic flexibilities provide improved energy conservation during impact of the golf club head and the golf ball. Materials used in the face section of the golf club head constitute an additional important factor in determining performance characteristics of coefficient of restitution (COR), launch angle, spin rate and durability.

One object of the present invention is to improve impact efficiency between a golf club head and the golf ball.

Another object is to designate a range of material properties to increase the static flexibility, otherwise described as reduced bending stiffness, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

Another object is to designate a range of material properties to increase the dynamic flexibility, otherwise

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described as reduced bending natural frequency, of the striking plate of the golf club head. Any number of materials having requisite limitations of stiffness and strength can be utilized in the manufacture of the golf club of the present invention to produce a compliant, or softer flexing performance during impact with the golf ball.

A further object of the present invention is a wood-type golf club head having a face section of a first material and a body section of a second material.

Another object of the present invention is a wood-type golf club head having a face section of a metal material.

Another object of the present invention is a wood-type golf club head having a face section of a non-metal material.

Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is a perspective view of a golf club head of an embodiment of the present invention.

FIG. 2 is a front view of a golf club head showing a striking plate with a major cross-section dimensional width (W) and a minor cross-section dimensional height (H).

FIG. 3a shows the striking plate of the golf club head of FIG. 2 with the major cross-section dimension (W) and the minor cross-section dimension.

FIG. 3b shows a striking plate having an elliptical shape with a major cross-section dimension (W) and a minor cross-section dimension (H).

FIG. 4 shows an elliptical plate with a pressure loading over a central circular region.

FIG. 5a shows the face section of the club head, of an embodiment of the present invention, prior to impact with the golf ball.

FIG. 5b shows deformation of the striking plate of the golf club head, of an embodiment of the present invention, during impact with the golf ball.

FIG. 5c shows an elliptical striking plate having a simply-supported edge constraint prior to impact with the golf ball.

FIG. 5d shows deformation of the elliptical striking plate of FIG. 5c during impact with the golf ball.

FIG. 5e shows an elliptical striking plate having a fixed edge constraint prior to impact with a golf ball.

FIG. 5f shows the elliptical striking plate of FIG. 5e during impact with the golf ball.

FIG. 6 is a plot of the normalized static and dynamic flexibility versus the face weight for a minimum weight design.

FIG. 7 is a plot of the bending natural frequency versus the static flexibility for a minimum thickness design.

FIG. 8 is a plot of the static flexibility versus striking plate thickness for a large club head utilizing five different materials for the golf club striking plate.

FIG. 9 is a plot of the natural frequency versus striking plate thickness for a large club head utilizing five different golf club striking plate materials.

DETAILED DESCRIPTION OF THE INVENTION

As shown in FIG. 1 a wood-type golf club head 10 comprises a face section 12, a rear section 14, a top section

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16, a bottom section 18, a toe section 20, a heel section 22 and a hosel inlet 24 to accept a golf shaft (not shown). The golf club head 10 is a unitary structure which may be composed of two or more elements joined together to form the golf club head 10. The face section 12, also called a striking plate, is an impact surface for contacting a golf ball (not shown). Structural material for the golf club head 10 can be selected from metals and non-metals, with a face material exhibiting a maximum limit for face stiffness and natural frequency being a preferred embodiment.

The present invention is directed at a golf club head 10 having a striking plate 12 that makes use of materials to increase striking plate flexibility so that during impact less energy is lost, thereby increasing the energy transfer to the golf ball. This increased energy transfer to the golf ball will result in greater impact efficiency. The striking plate 12 is generally composed of a single piece of metal or nonmetallic material and may have a plurality of score-lines 13 thereon. The striking plate 12 may be cast with a body 26, or it may be attached through bonding or welding to the body 26. See FIGS. 1 and 2.

For explanation purposes, the striking plate 12 is treated as an elliptical shaped cross section having a uniform thickness, denoted as "t" in FIG. 4, that is subjected to a distributed load over a small circular region at the center of the striking plate 12. See FIGS. 3 and 4. Those skilled in the pertinent art will recognize that striking plates having other shapes, nonuniform thickness distribution, and force locations are within the scope and spirit of the present invention. The overall cross-section width is given by (W=2a), the overall cross-section height (H=2b), and the striking plate aspect ratio is defined as ($\alpha=b/a$). The impact load, resulting from impact of the golf ball with the golf club head 10, is treated as force of magnitude (F), acting with a pressure (q) over a circular region of radius (r_o) in the center of the elliptical plate so that

$$F = \int_0^{2\pi} \int_0^{r_o} q r dr d\theta. \quad (I)$$

Like other striking plates of the prior art, the striking plate 12 of the present invention is positioned between the top section 16 and bottom section 18. During impact with the golf ball, the striking plate 12 will deflect depending upon the connection to the top section 16 and the bottom section 18, see FIG. 5a-f. The two extreme limiting cases for all possible boundary attachment conditions are defined as "simply-supported" where the elliptical edge of the striking plate is constrained from translating but the edge is free to rotate, see FIGS. 5c and 5d, and "fixed" or "clamped" where the elliptical edge is fixed from both translating and rotating, see FIGS. 5e and 5f. The boundary attachment for the striking plate 12 to the body 26 of the club head 10 will fall between the two limiting cases since the top section 16 and bottom section 18 will provide some stiffening to the striking plate 12, but in general are very close to the simply supported condition. The calculated maximum stress in the striking plate as a result of the applied loading is

$$\sigma = \frac{3(1+\nu)RF^*}{2\pi t^2} \quad (II)$$

where (F*) is the maximum load that includes the effects of design safety factors and the score-line 13 stress concentration factors, (t) is the plate thickness, (ν) is the material Poisson ratio, and (R) depends upon the plate geometry

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(a,b), load radius, material Poisson ratio, and edge support conditions. For golf club heads, the top section 16 and bottom section 18 provide some stiffening to the striking plate 12 edge, (R) will fall between the simply-supported edge and the fixed support, but for this invention it is very close to the simply-support edge condition;

$$R_{\text{simply-support}} = \ln\left(\frac{b}{r_o}\right) + \frac{\nu}{(1+\nu)}(6.57 - 2.57\alpha) \quad (\text{III.a, b})$$

$$R_{\text{fixed}} = \ln\left(\frac{2b}{r_o}\right) - .317\alpha - .376.$$

The minimum required thickness of the striking face based upon the applied loading is determined by setting the maximum stress to the allowable material yield stress (σ_{yield}) and solving;

$$t = \sqrt{\frac{3(1+\nu)RF^*}{2\pi\sigma_{\text{yield}}}}. \quad (\text{IV})$$

The minimum required striking plate thicknesses for two different materials (materials A and B) can be directly compared using Equation (IV), if one assumes that the impact forces, the plate geometry (W, H), and the edge boundary constraints are nearly the same. Writing the ratio of the minimum required thicknesses for two different materials is

$$\frac{t_A}{t_B} = \sqrt{\left(\frac{\sigma_{\text{yield-B}}}{\sigma_{\text{yield-A}}}\right)\left(\frac{1+\nu_A}{1+\nu_B}\right)}, \quad (\text{V})$$

where (t_A) and (t_B) are the minimum required thicknesses for plates composed of materials A and B, respectively, and ($\sigma_{\text{yield-A}}$, ν_A) and ($\sigma_{\text{yield-B}}$, ν_B) are the material properties of A and B, respectively. A weight ratio comparison of two minimum thickness striking plates is equal to

$$\frac{W_A}{W_B} = \frac{\rho_A t_A \pi a b}{\rho_B t_B \pi a b} = \frac{\rho_A}{\rho_B} \sqrt{\left(\frac{\sigma_{\text{yield-B}}}{\sigma_{\text{yield-A}}}\right)\left(\frac{1+\nu_A}{1+\nu_B}\right)}, \quad (\text{VI})$$

where (ρ_A) and (ρ_B) are the densities of material A and B, respectively, and these plates have identical geometry (W, H), boundary constraints, and are designed to withstand the same load (F^*).

Static Flexibility

The calculated striking plate static flexibility (S), which is the inverse of the plate stiffness, is defined as the calculated center displacement of the striking plate 12 divided by the plate force (F^*) and is equal to:

$$S = \frac{b^2}{Et^3} P, \quad (\text{VII})$$

where (b) is half the height of the striking plate 12, (E) is Young's modulus and (P) depends upon the geometry and the support conditions of the elliptical plate. For golf heads, (P) will fall between the simply-supported and fixed edge conditions, but for this invention it falls very close to the simply-supported edge condition;

$$P_{\text{simply-sup por}} = (0.76 - 0.18\alpha)$$

$$P_{\text{fixed}} = (0.326 - 0.104\alpha) \quad (\text{VIII.a,b})$$

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Thus, increased striking plate flexibility can be accomplished by increasing the striking plate height (b), decreasing the Young's modulus (E), also described as material stiffness, or by reducing the plate thickness (t). But the plate thickness can only be reduced to the minimum allowable thickness from Equation (IV). Substituting Equation (IV) into (VII), results in the static flexibility having a minimum allowable plate thickness;

$$S = \left[\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{3/2} \right] \left[P b^2 \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right], \quad (\text{IX})$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (P, R), and impact load definition (F^*). Assuming the plate geometry, edge attachment, and the impact load are the same for two different designs (second bracketed term of Equation IX), then to maximize the static flexibility, one needs to select a material having the largest ratio of:

$$\frac{1}{E} \left(\frac{\sigma_{\text{yield}}}{1+\nu} \right)^{3/2}. \quad (\text{X})$$

The static flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (IX) as a ratio

$$\frac{S_A}{S_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{\sigma_{\text{yield-A}}}{\sigma_{\text{yield-B}}} \right)^2 \left(\frac{1+\nu_B}{1+\nu_A} \right)^2, \quad (\text{XI})$$

where (S_A) and (S_B) are the static flexibilities of a plate having a minimum plate thickness for materials A and B, respectively and (E_A) and (E_B) are the material stiffnesses for materials A and B, respectively.

Bending Natural Frequency

The calculated bending natural frequency (ω), or referred to simply as natural frequency, having units of cycles/second (Hz), for the elliptical striking plate is given by;

$$\omega \text{ (Hz)} = \frac{\lambda t}{b^2} \sqrt{\frac{Eg}{\rho(1-\nu^2)}} \quad (\text{XII})$$

where (ν) is the material Poisson ratio, (b) is half the height of the striking plate 12, (ρ) is the material weight density, (g) is the gravitational constant (32.2 ft/sec²), and (λ) depends upon the geometry and the support conditions of the elliptical plate, as well as the desired vibration mode. For golf club heads, (λ) will fall between the two limiting edge support values, simply-support and fixed, but for this invention it is very close to the simply-support condition;

$$\lambda_{\text{simply-sup por}} = 0.124 \sqrt{1 + 0.21\alpha + 2.37\alpha^2 - 3.03\alpha^3 + 2.7\alpha^4}$$

$$\lambda_{\text{fixed}} = 0.2877 \sqrt{1 + 2/3\alpha^2 + \alpha^4} \quad (\text{XIII.a,b})$$

The bending natural frequency can be minimized by increasing the striking plate 12 height (2b) or aspect ratio (α), increasing the material density (ρ), decreasing the material stiffness (E), or decreasing the plate thickness (t). But the plate thickness can only be reduced to the minimum allow-

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able thickness from Equation (IV). Substituting Equation (IV) into (XII), results in the natural frequency having a minimum allowable plate thickness;

$$\omega = \left[\sqrt{\frac{E}{\sigma_{yield}\rho(1-\nu)}} \right] \left[\frac{\lambda}{b^2} \sqrt{\frac{3gRF^*}{2\pi}} \right] \quad (XIV)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are the fixed (second bracketed term of Equation XIV), then to minimize the natural frequency, one needs to select a material having the smallest of:

$$\frac{E}{\sigma_{yield}\rho(1-\nu)} \quad (XV)$$

The natural frequency of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XIV) as a ratio

$$\frac{\omega_A}{\omega_B} = \sqrt{\left(\frac{E_A}{E_B} \right) \left(\frac{\sigma_{yield-B}}{\sigma_{yield-A}} \right) \left(\frac{\rho_B}{\rho_A} \right) \left(\frac{1-\nu_B}{1-\nu_A} \right)}, \quad (XVI)$$

where (ω_A) and (ω_B) are the natural frequencies of a striking plate having a minimum plate thickness for materials A and B.

A golf club head has a large number of natural frequencies, where some involve the vibratory motion that characterize the striking plate, others involve motion that characterize the top plate or bottom plate, and still others involve the combined motion of the striking plate and other parts of the club head. The natural frequencies that are of concern in the present invention involve the full or partial vibratory motion of the striking plate. Thus, to experimentally measure these frequencies, one needs to excite the striking plate as well as record its response. A noncontacting excitation and response system is preferred to insure that added mass or stiffness effects do not artificially alter the results. In our experimental studies, the striking plate was excited using either an impact hammer (PCB Inc. of Buffalo, N.Y., model 068, series 291; or Kistler Instrument Corp. of Amherst, N.Y., model 9722A500) or an acoustical funnel-cone speaker, where the speaker is driven with broad-band "white" random noise between 1000–10,000 Hz. The velocity time history (response) is measured using a laser velocimeter (Polytec PI GmbH of Waldbronn, Germany, model OFV-303 or PSV-300; or Ometron Inc. of London, England, model VPI-4000). The recorded excitation and response time histories are processed using a two-channel spectrum analyzer (Hewlett Packard of Palo Alto, Calif.) to determine the frequency content of the response signal divided by the excitation signal. The spectrum analyzer has input/output windowing features and anti-aliasing filters to eliminate processing errors. The test is repeated a minimum of 10 times and the data is averaged to minimize the effects of uncorrelated noise. Thus the coherence was found to be greater than 0.98 at all measured natural frequencies. The tests are repeated using numerous excitation and response locations on the striking plate to insure that the lowest striking plate dominated natural frequencies are recorded.

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Dynamic Flexibility

The dynamic flexibility (D) for the striking plate is given by

$$D = \frac{1}{m_e(2\pi\omega)^2}, \quad (XVII)$$

where, (ω) is the striking plate natural frequency, and (m_e) is the effective face mass that contributes to the dynamic response during impact:

$$m_e = \beta \frac{\rho}{g} \pi t a b = \beta \frac{\rho}{g} \pi t \frac{b^2}{\alpha}. \quad (XVIII)$$

Here (β) is defined between (0) and (1), where (0) is associated with no face mass contributing to the dynamic response and (1) having all of the face mass contributing to the response. For golf clubs, ($0.15 < \beta < 0.35$). Writing the dynamic flexibility by substituting Equations (XIV) and (XVIII) into (XVII):

$$D = \frac{b^2}{E t^3} \left(\frac{\alpha(1-\nu^2)}{4\beta\pi^3\lambda^2} \right), \quad (XIX)$$

The striking plate dynamic flexibility can be increased by enlarging the plate depth (b) or aspect ratio (α), decreasing the material stiffness (E), or decreasing the plate thickness (t). Clearly the greatest increase in (D) can be found by changing the thickness (t), followed by changing the face height (2b). But, the plate thickness can only be reduced up to the allowable value of Equation (IV). Thus, the maximum dynamic flexibility (D) for a given plate geometry and applied load is calculated by substituting the minimum allowable thickness Equation (IV) into (XIX);

$$D = \left[\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \right] \left[\left(\frac{a b^2}{4\beta\pi^3\lambda^2} \right) \left(\frac{2\pi}{3RF^*} \right)^{3/2} \right] \quad (XX)$$

where the first bracketed term depends upon the striking plate material properties, the second bracketed term depends upon the face geometry (a, b, α), edge attachment constraints (λ , R), and impact load definition (F*). Assuming the plate geometry, edge attachment, and the impact load are constant (second bracketed term of Equation XX), then to maximize the dynamic flexibility (D), one needs to select a material having the largest ratio of:

$$\frac{(1-\nu^2)}{E} \left(\frac{\sigma_{yield}}{(1+\nu)} \right)^{3/2} \quad (XXI)$$

The dynamic flexibility of two materials (A) and (B) can be compared, for a given plate geometry, edge attachments, and applied load by writing Equation (XX) as a ratio

$$\frac{D_A}{D_B} = \left(\frac{E_B}{E_A} \right) \left(\frac{1-\nu_A^2}{1-\nu_B^2} \right) \left(\frac{\sigma_{yield-A}}{\sigma_{yield-B}} \right)^{3/2} \left(\frac{1+\nu_B}{1+\nu_A} \right)^{3/2}, \quad (XXII)$$

where (D_A) and (D_B) are the maximum dynamic flexibilities of a plate having a minimum plate thickness for materials A and B, respectively.

For wood-type golf clubs the following geometry and force properties are typical (a=1.4–1.65 inch, b=0.7–1.0 inch, t=0.14–0.25 inch, F*=2000–15,000 lbs). In Table 1,

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current metal golf club head material properties are given along with five different golf club head property ratios. These five different ratios include: minimum required striking plate thickness (Eq. V), resulting striking plate weight (Eq. VI), static flexibility (Eq. XI), bending natural frequency (Eq. XVI), and dynamic flexibility (Eq. XXII), where the baseline (B) material is taken as (17-4) Stainless Steel. These ratios provide a comparison of striking plates that have identical elliptical geometry, edge attachment, and load capacity, but are composed of different materials and thus will have different minimum striking plate thicknesses. A normalized comparison of the static flexibility and dynamic flexibility to face weight is presented in FIG. 6, where all results are normalized to an equivalent (17-4) Stainless Steel striking plate. In FIG. 6, it is clear that the amorphous alloy striking plate and maraging striking plate offer (4.8) and (2.5) times more flexibility and lower face weight than stainless steel as a result of their high strength, while the titanium alloy striking plate offers 50% more flexibility and lower face weight as a result of significantly lower modulus, but that the aluminum alloy striking plate

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embodiment the striking plate of aluminum alloy has a maximum thickness of less than 0.200 inches, and more preferably between 0.200 and 0.070 inches. The striking plates composed of an amorphous alloy, Maraging 280 steel, and the 6-4 Titanium all have static and dynamic flexibilities much greater than the 17-4 Stainless Steel striking plate (480%, 240% and 150%), while the aluminum alloy striking plate has a 12% lower flexibility as a result of its large thickness. Finally, the striking plates composed of amorphous alloy and maraging steel have bending natural frequencies which are 41% and 27% lower, respectively, than the 17-4 Stainless Steel striking plate, whereas the titanium alloy striking plate is nearly the same as the stainless steel, while the aluminum alloy striking plate is 50% greater as a result of an increased thickness and low density.

It should be further pointed out, that most golf club designers use the striking plate weight savings to further increase the size of the striking plate (i.e. oversize titanium drivers) and thus further increase its static and dynamic flexibility.

TABLE 1

Typical Material Properties used in Golf Club Faces and Comparison Ratios									
Material (i)	E 10 ⁶ lb/in ²	ν	σ_{yield} 10 ³ lb/in ²	ρ lb/in ³	t_i/t_{steel}	W_i/W_{steel}	S_i/S_{steel}	$\omega_i/\omega_{\text{steel}}$	D_i/D_{steel}
Stainless Steel(17-4)	29.0	.27	150	.276	1.00	1.00	1.00	1.00	1.00
Aluminum (7075-T6)	10.4	.33	73	.101	1.47	0.54	0.88	1.48	0.85
Titanium (Ti 6-4)	16.0	.31	138	.160	1.06	0.61	1.53	1.05	1.49
Maraging 280 Steel	26.5	.31	262	.285	0.77	0.79	2.41	0.73	2.35
Amorphous Alloy	13.3	.30	260	.220	0.77	0.61	4.80	0.59	4.72

results in lower flexibility as a result of its lower strength. These increases in flexibility lead to reduced impact energy losses, which in turn lead to greater golf ball flight velocities. In FIG. 7, a comparison of normalized face natural frequency versus static flexibility is presented, where a correlation exists between measured natural frequency and static flexibility, and thus natural frequency can be used as a simple nondestructive measurement technique for assessing the magnitude of the static and dynamic flexibility. It is observed that the amorphous alloy and maraging steel striking plates have a lower natural frequency and greater flexibility than other materials in FIG. 7 because of their high strength and density. The titanium alloy striking plate and aluminum alloy striking plate have natural frequencies higher than all the other materials in FIG. 7 because of their low density.

A detailed inspection of Table 1 reveals that striking plates composed of Maraging 280 steel or the amorphous alloy are 23% thinner than the 17-4 Stainless Steel striking plate, which is a direct result of higher strength of these materials. In a preferred embodiment the striking plate of stainless steel has a maximum thickness of less than 0.130 inches, and more preferably between 0.130 and 0.070 inches, while both the maraging steel and amorphous alloy have a striking plate thickness of less than 0.100 inches, and more preferably between 0.100 and 0.070 inches. The Aluminum 7075-T6 striking plate is thickest because of its low strength, but it is the lightest as a result of its low density. In a preferred

As a second example, consider a very large oversized driver head similar to a Callaway Golf® Biggest Big Bertha driver that is fabricated with different material striking plates. The geometry values are defined as (a=1.65 inch, b=0.875 inch, $\alpha=0.530$). In order to produce striking plate flexibility levels greater than found in any current club-head: (1) the striking plate has no scorelines, thus ($F^*=2500$ lbs) with a radius ($r_s=0.50$ inch), and (2) the edge attachment condition is nearly simply-supported so that ($P=0.664$, $\lambda=0.1538$). Constructing the striking plate out of Titanium (Ti 6-4), leads to ($R=1.792$) and a minimum required face thickness of ($t=0.143$ inch). Including score-line stress concentration factors will simply increase (F^*), thus increasing the required face thickness (t) and bending natural frequency, and decreasing the flexibility. The calculated weight is ($W=0.103$ lb), the static flexibility is ($S=1.10 \times 10^{-5}$ in/lb), the natural frequency ($\omega=5920$ Hz), and the dynamic flexibility ($D=1.08 \times 10^{-5}$ in/lb), where it was assumed ($\beta=0.25$). The calculated head natural frequency of 5920 Hz is within 2% of the experimentally measured value of 6040 Hz on an actual experimental hybrid golf club head. The maximum displacement of the striking plate is found by multiplying the static flexibility and the effective force (F^*), thus ($\Delta=0.0275$ inch). Hybrid golf club heads having different material striking face plates are presented in Table 2, where the striking plates have minimum allowable face thicknesses. In FIGS. 8 and 9, the variation of the static flexibility and natural frequency with striking plate thickness is pre-

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sented for the five different metals, where the symbol (o) is used to represent the minimum allowable thickness for a assumed applied load ($F^*=2500$ lbs). Clearly, if the applied load were increased then the minimum allowable thicknesses would increase, where the symbols would just move to the right along the appropriate curve. Thus lowering the flexibility and increasing the natural frequency. Moreover, if a higher strength version of an alloy were used, then the

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preferred embodiment the natural frequency is between 5400 Hz and 2800 Hz. For the maraging steel striking plate 12, the natural frequency is below 6000 Hz, and in a more preferred embodiment the natural frequency is between 6000 Hz and 2800 Hz. For the amorphous alloy striking plate 12, the natural frequency is below 5500 Hz, and in a more preferred embodiment the natural frequency is between 5500 Hz and 2800 Hz.

TABLE 2

Calculated Striking Plate Properties for a Hybrid Oversized Driver Golf Club Head without scorelines ($a = 1.65"$, $b = .875"$, $\alpha = .530$, $F^* = 2500$ lb, $r_0 = 0.5"$, $P = 0.664$, $\lambda = .154$, $\beta = 0.25$).											
Material (i)	E 10^6 lb/in ²	ν	σ_{yield} 10^3 lb/in ²	ρ lb/in ³	R	T Inch	W lb	S 10^{-5} in/lb	Δ inch	ω (Hz)	D 10^{-5} in/lb
Stainless Steel(17-4)	29.0	.27	150	.276	1.67	.130	.162	.803	.020	5458	.809
Aluminum (7075-T6)	10.4	.33	73	.101	1.85	.200	.092	.605	.015	8520	.586
Titanium (Ti 6-4)	16.0	.31	138	.160	1.79	.142	.103	1.10	.027	5920	1.08
Maraging 280 Steel	26.5	.31	262	.285	1.79	.103	.134	1.74	.043	4143	1.71
Amorphous Alloy	13.3	.30	260	.220	1.76	.102	.102	3.55	.089	3301	3.51

symbol would follow the curve to the left and thus increase the flexibility and lower natural frequency. It is observed that the greatest flexibility occurs for maraging steel and the amorphous alloy, which has the thinnest striking plates and lowest natural frequencies.

It is known through experimental testing, that currently available driver golf club heads have striking-face natural frequencies greater than 4500 Hz. Moreover, the only commercially available golf club head with an amorphous alloy striking plate (commercial name: Liquid Metal™) has a fundamental striking plate natural frequency of 5850 Hz. Thus, the striking plates on these club heads are not optimized for maximum flexibility. They do not have a minimum thickness striking plate, a large aspect ratio, or an edge support that simulates the simply supported constraint. From Equation XVII, the dynamic flexibility is inversely proportional to the square of the natural frequency, thus these heads have a flexibility that is much lower and a face thickness that is much greater than the optimized minimum values presented in the previous example (i.e. their values on FIGS. 8 and 9 would be to the far right of the minimum allowable thickness). In a preferred embodiment of the present invention, the material of striking plate 12 has a natural frequency of less than 4500 Hz, in a more preferred embodiment the striking plate 12 natural frequency is between 4500 Hz and 2800 Hz. For the aluminum alloy striking plate 12, the natural frequency is below 8500 Hz, and in a more preferred embodiment the natural frequency is between 8500 Hz and 2800 Hz. For the titanium alloy striking plate 12, the natural frequency is below 5900 Hz, and in a more preferred embodiment the natural frequency is between 5900 Hz and 2800 Hz. For the stainless steel striking plate 12, the natural frequency is below 5400 Hz, and in a more

Although the above description is for wood-type golf club heads having an elliptical face section, the present invention is not limited to such an embodiment. Also included within the bounds of the present invention are iron type golf club heads and golf club heads with α values approaching 1.0.

The golf club head 10 is a fairway wood or a driver. The golf club head 10 has a body 26, excluding the striking plate 12, that is preferably composed of a metal material such as titanium, titanium alloy, stainless steel, or the like, and is most preferably composed of a forged titanium material. However, the body 26, or a portion of the body 26, may be composed of a graphite composite material or the like. The body 26 preferably has a large volume, most preferably greater than 300 cubic centimeters, more preferably 300 cubic centimeters to 450 cubic centimeters, even more preferably 350 cubic centimeters to 400 cubic centimeters, and is most preferably 385 cubic centimeters for a body composed of titanium, or titanium alloy. However, a body 26 composed of stainless steel may have a volume range of 200 cubic centimeters to 325 cubic centimeters, and a body 26 composed of a composite material (such as plies of continuous carbon fiber pre-preg material) may have a volume of 325 cubic centimeters to 600 cubic centimeters. The body 26 preferably weighs no more than 215 grams, and most preferably weighs between 180 and 205 grams. The body 26 has a hollow interior.

From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing

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except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

I claim as my invention:

1. A wood-type golf club head comprising:
a striking plate composed of a titanium alloy material and having a thickness less than 0.200 inch and greater than 0.070 inch, the striking plate having a natural frequency of less than 4500 Hz and greater than 2800 Hz.

2. The wood-type golf club head according to claim 1 wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

3. A wood-type golf club head comprising:

a striking plate disposed in the open front of the body, the striking plate composed of a titanium alloy material and having a thickness less than 0.140 inch, the striking plate having a plurality of scorelines thereon, the strik-

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ing plate having a natural frequency of less than 8500 Hz and greater than 2800 Hz.

4. A wood-type golf club head comprising:

a body having a striking plate, the striking plate composed of a forged titanium alloy material and having a thickness less than 0.140 inch, the striking plate having a plurality of scorelines thereon, the striking plate having a natural frequency of less than 4500 Hz and greater than 2800 Hz, the golf club head having a volume ranging from 300 cubic centimeters to 450 cubic centimeters.

5. The wood-type golf club head according to claim 4 wherein the natural frequency is less than 3300 Hz and greater than 2800 Hz.

6. The wood-type golf club head according to claim 4 wherein the volume is 385 cubic centimeters.

* * * * *

CIVIL COVER SHEET

The JS-44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM.)

I. (a) PLAINTIFFS

CALLAWAY GOLF COMPANY

(b) County of Residence of First Listed Plaintiff San Diego County, California
(EXCEPT IN U.S. PLAINTIFF CASES)**DEFENDANTS**

ACUSHNET COMPANY

County of Residence of First Listed Defendant Bristol County, Massachusetts
(IN U.S. PLAINTIFF CASES ONLY)NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE
LAND INVOLVED

(c) Attorneys (Firm Name, Address, and Telephone Number)

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(302) 652-5070

Attorneys (If Known)

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

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- ☒ 3. Federal Question (U.S. Government Not a Party)
- ☐ 2. U.S. Government Defendant
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V. ORIGIN

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- ☐ 6 Multidistrict Litigation
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Patent infringement under 35 USC

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Thomas L. Halkowski

TYPE NAME OF ATTORNEY

Thomas L. Halkowski

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MAG. JUDGE

Authority for Civil Cover Sheet

The JS-44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

I. (a) Plaintiffs – Defendants. Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.

(b) County of Residence. For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the “defendant” is the location of the tract of land involved.)

(c) Attorneys. Enter the firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section “(see attachment)”.

II. Jurisdiction. The basis of jurisdiction is set forth under Rule 8(a), F.R.C.P., which requires that jurisdictions be shown in pleadings. Place an “X” in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.

United States plaintiff. (1) Jurisdiction based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States are included here.

United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an “X” in this box.

Federal question. (3) This refers to suits under 28 U.S.C.1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, and act of Congress or a treaty of the United States. In cases where the U.S. agency is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.

Diversity of citizenship. (4) This refers to suits under 28 U.S.C.1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked. (See Section III below; federal question actions take precedence over diversity cases.)

III. Residence (citizenship) of Principal Parties. This section of the JS-44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.

IV. Nature of Suit. Place an “X” in the appropriate box. If the nature of suit cannot be determined, be sure the cause of action, in Section VI below, is sufficient to enable the deputy clerk or the statistical clerks in the Administrative Office to determine the nature of suit. If the cause fits more than one nature of suit, select the most definitive.

V. Origin. Place an “X” in one of the seven boxes.

Original Proceedings. (1) Cases which originate in the United States district courts.

Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441. When the petition for removal is granted, check this box.

Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.

Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.

Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a). Do not use this for within district transfers or multidistrict litigation transfers.

Multidistrict Litigation. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407. When this box is checked, do not check (5) above.

Appeal to District Judge from Magistrate Judgment. (7) Check this box for an appeal from a magistrate judge’s decision.

VI. Cause of Action. Report the civil statute directly related to the cause of action and give a brief description of the cause.

VII. Requested in Complaint. Class Action. Place an “X” in this box if you are filing a class action under Rule 23, F.R.C.P.

Demand. In this space enter the dollar amount (in thousand of dollars) being demanded or indicate other demand such as a preliminary injunction.

Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.

VIII. Related Cases. This section of the JS-44 is used to reference related pending cases if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CALLAWAY GOLF COMPANY,

Plaintiff,

v.

ACUSHNET COMPANY,

Defendant.

Civil Action No.

NOTICE OF RELATED CASE UNDER DELAWARE LOCAL RULE 3.1

Delaware Civil Local Rule 3.1(b) provides that “Counsel for a plaintiff in a civil action shall indicate on the civil cover sheet if such action and one or more other civil actions or proceedings previously decided or currently filed in this District or any other court: (1) arise from the same or substantially identical transactions, happenings, or events; (2) involve the same or substantially the same parties or property; (3) involve the same patent or the same trademark; or (4) for other reasons would entail substantial duplication of labor if heard by different judges. Pursuant to this rule, Callaway Golf Company submits the following statement under Local Rule 3.1(b)(2).

This is an action for infringement of U.S. Patent Nos. 6,348,015, 6,478,692, 6,669,579, 6,685,576, and 6,949,032, all of which are owned by Callaway Golf. These patents are all related, all are entitled “Golf Club Head Having A Striking Face With Improved Impact Efficiency,” and all relate to inventions by Dr. John B. Kosmatka. Callaway Golf alleges that certain *clubs* sold by Acushnet under the Cobra and Titleist brands infringe the patents-in-suit.

A case captioned *Callaway Golf Co. v. Acushnet Co.*, C.A. No. 06-91 (SLR), the

Honorable Sue L. Robinson presiding, is currently pending in this Court. In that case, Callaway Golf alleges that certain golf **balls** sold by Acushnet under the Titleist brand infringe U.S. Patent Nos. 6,210,293, 6,503,156, 6,506,130, and 6,595,873. The technology, products, and patents at issue in the pending matter are completely different from the technology, products and patents in the instant case. Nevertheless, Callaway Golf provides this notice of the pending case pursuant to Local Rule 3.1(b)(2) because it involves the same parties as the instant case.

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AO FORM 85 RECEIPT (REV. 9/04)

United States District Court for the District of Delaware

07-367

Civil Action No. _____

FILED
U.S. DISTRICT COURT
DISTRICT OF DELAWARE

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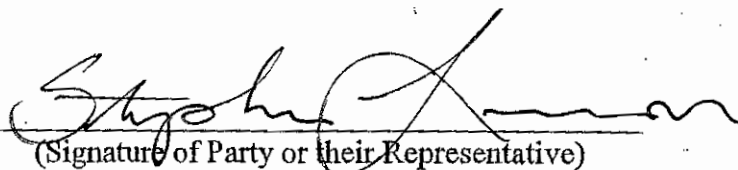
ACKNOWLEDGMENT
OF RECEIPT FOR AO FORM 85

NOTICE OF AVAILABILITY OF A
UNITED STATES MAGISTRATE JUDGE
TO EXERCISE JURISDICTION

I HEREBY ACKNOWLEDGE RECEIPT OF 2 COPIES OF AO FORM 85.

JUN 08 2007

(Date forms issued)


(Signature of Party or their Representative)

Stephen Lennon
(Printed name of Party or their Representative)

Note: Completed receipt will be filed in the Civil Action